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ABSTRACT

This report of the Committee on National Needs for the Rehabilitation of the Physically Handicapped focuses on the current problems in the field, the areas in which additional knowledge is needed, and directions in which the society and government should move both with respect to the acquisition of knowledge and a more effective organization of effort. Listed among recommendations is that for major areas of disability. A comprehensive national overview should be developed outlining in full its demography, national cost, and related social and organizational structure. Rehabilitation is discussed in terms of the medical and social framework, demography, organizations and programs, the policy picture, and economics. A section on the state of the art in science and technology and their application covers research and development, blindness and low vision, hearing and speech, manipulation and locomotion, and basic neuroscience and rehabilitation. (Author/BB)

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National Research Council, Washington, D C

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Prepared for

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Dec 76

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Science and Technology in the Service of the Physically Handicapped

Volume 1

Committee on National Needs for the Rehabilitation of the Physically Handicapped

Division of Medical Sciences

Assembly of Life Sciences

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16. Abstracts

The report defines current problems in the field of rehabilitation, highlights areas in which additional knowledge is needed, and points to directions in which our society and our government should move, both with respect to the acquisition of new knowledge and with respect to a more effective organization of effort. The Committee on National Needs for the Rehabilitation of the Physically Handicapped examines broadly what needs to be done to improve the utilization of science and technology in restoring physically handicapped individuals to more active roles in society. A strong NAS-NRC role is recommended in the establishment of a "multiprofessional mechanism of sufficient quality and visibility...to assist both the public and private sectors in formulating a strategy that is effective in providing the needed devices and services for the physically handicapped and in aggregating resources and markets to this end."

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SCIENCE AND TECHNOLOGY IN THE SERVICE OF THE PHYSICALLY HANDICAPPED

VOLUME I

Committee on National Needs for the Rehabilitation of the Physically Handicapped

Division of Medical Sciences

Assembly of Life Sciences

National Research Council

National Academy of Sciences

Washington, D.C. 1976

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

NATIONAL ACADEMY OF SCIENCES

OFFICE OF THE PRESIDENT
2101 CONSTITUTION AVENUE
WASHINGTON, D. C. 20418

November 8, 1976

The Honorable David Mathews
Secretary of Health, Education,
and Welfare
330 Independence Avenue, S.W.
Washington, D. C. 20201

and

The Honorable Richard L. Roudebush
Administrator of Veterans Affairs
Veterans Administration
810 Vermont Avenue, N.W.
Washington, D. C. 20420

Gentlemen:

I am pleased to transmit herewith the report, "Science and Technology in the Service of the Physically Handicapped."

The concern of the National Academy of Sciences for the needs of the disabled and handicapped members of our society has deep roots, reaching back to World War II when the Academy undertook a program to improve the quality and availability of prosthetic and orthotic devices for military amputees. Ever since, the Academy and its National Research Council have had a significant and continuing role in the development, evaluation and utilization of new devices to assist the disabled and in the education and training of individuals to serve their needs. This has been made possible by financial support from the wartime Office of Scientific Research and Development, and later from the Army, the Veterans Administration and agencies of the Department of Health, Education, and Welfare. The nation is deeply indebted to the many scientists, clinicians and engineers who, as members and associates of the National Research Council Committee on Prosthetics Research and Development and its predecessor groups, gave generously of their time and knowledge to advance our ability to be helpful to the physically handicapped.

The Academy's involvement with the physically handicapped began with concern for the specific problems of veterans and later expanded to consideration of assistance to all physically disabled persons. Attention was long focussed on the design and utilization of diverse prosthetic appliances and devices, taking advantage of the knowledge and skills to be found in the scientific and engineering communities, then expanded to concern for the entire array of technical, clinical, educational, psychological and social services that should be made available to assist physically handicapped persons to lead useful and productive lives and have reasonable opportunity to compete in our society. It was recognition of this expanded set of considerations that led to the appointment in April 1975 of the Committee on National Needs for the Rehabilitation of the Physically Handicapped.

The committee was requested to examine broadly what needs to be done to improve the utilization of science and technology in restoring physically handicapped individuals to more active roles in society. This report makes it evident that while we can take some measure of pride in what has been accomplished, much, much more remains to be done. It is my hope that this report of our study of these problems will be useful to you and to others who bear responsibility for assisting our handicapped fellows. It is my further hope that this Academy will be privileged to assist in meeting the goals here set forth.

Finally, may I take this opportunity publicly to convey to Professor Rosenblith and his committee our deepest appreciation.

Sincerely yours,

Philip Handler
President

Enclosure

PREFACE

Physical handicaps sharply reduce our nation's human resources and add considerably to human suffering and to our society's economic burden. Estimates of the number of persons in the United States who are physically handicapped vary considerably depending upon the definition and severity of the handicap. Given the difficulties of obtaining a reliable estimate, one must be aware that these numbers vary all the way from 6 to 28 million* persons, with the greatest uncertainty at both ends of the age spectrum.

Some recent estimates by the Social Security Administration place the number of physically disabled individuals who are limited in work activities around eight million. In addition, an estimated seven and one-half million are unable to work at all. Millions more, either too young or too old to work, are limited in their daily activities. Estimates of the financial burden of physical disability in the United States are thus, understandably, unreliable and crude. Figures ranging from several billions of dollars to several tens of billions can be found in the literature, providing little basis for an estimate that would stand up to criticism. In addition to the burden borne by the handicapped and their families, this financial burden is borne by federal and state programs, of which there are many (more than 103 federal programs are listed by the Office for Handicapped Individuals (1)).

The data available indicate that this burden is increasing if only because the number of aged is increasing and because the number of chronically ill and severely injured persons surviving continues to increase because of advances in medical care. Added to the loss in productivity are the personal losses suffered by the physically handicapped from limitations imposed on their ability to participate in many aspects of life--losses that cannot be measured in dollars.

Only a very small fraction of the country's scientific and technological capabilities have been effectively utilized to aid the physically handicapped. Few devices commonly used by the handicapped show the influence of current technology at all; many devices such as wheelchairs, which are produced by a multimillion-dollar industry, have been virtually unchanged for decades. Compared to the costs of rehabilitation and compensation for physical handicaps, only a minute fraction goes to research and development concerned directly with the needs of the handicapped.

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*The Swedish Institute for the Handicapped estimates that in Sweden in 1975-1976, more than 1 million of the 8 million inhabitants were handicapped (data from Birger Roos, Technical Director, Handikappinstitutet, August 24, 1976). Approximately 12% of the Swedish population are considered handicapped, a figure in good agreement with the higher estimate above for the United States.

The National Academy of Sciences-National Research Council, aware that with the aid of science and technology within an appropriate institutional and societal setting large numbers of handicapped individuals might be restored to more productive and normal lives, established the Committee on National Needs for the Rehabilitation of the Physically Handicapped in April 1975. The Committee was to examine broadly what needs to be done to improve the utilization of science and technology in restoring physically handicapped individuals to more active roles in society. The prevalence of chronic conditions is necessarily greater in the adult and especially the aged segments of the population than in the young; but the Committee is also acutely sensitive to the special needs of children, especially the congenitally handicapped. It is estimated that about 3 percent of all schoolage children are significantly handicapped. Many of these children require special assistance in acquiring skills they have never had. Thus they require habilitation for essential functions, rather than rehabilitation. For this report, however, the needs of the handicapped population were considered as a whole. Little attempt was made to consider the multiply handicapped separately or to analyze the components of the population by age or by cause of the handicapping condition. Further, because of limited time and resources, the Committee decided to limit the state of the art review to blindness and low vision, hearing and speech problems, and difficulties with manipulation and locomotion.

The charge to the Committee was (a) to assess the nation's needs regarding the application of science and technology to aid the physically handicapped, (b) to formulate specific plans of action to meet those needs, and (c) to specify how the NAS-NRC might best help meet the nation's needs in this area.

The Committee first met in April 1975 to receive its charge and to plan its work. An intensive workshop, on the needs and problems of the handicapped was held in Woods Hole, Massachusetts from June 21 through July 1, 1975. The work of the Committee is detailed in the Appendix.

Volume 1 comprises the Committee's report. Volume 2 contains six papers on social science and policy in areas essential to the evaluation of the needs of the handicapped but not represented by the Committee membership. These papers were contributed by consultants at the request of the Committee.

The objective of the Committee's report is to indicate the current problems in the field, to highlight the areas in which we need additional knowledge, and to point out directions in which our society and our government should move, both with respect to the acquisition of new knowledge and with respect to a more effective organization of effort.

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The work of the Committee was supported by the Rehabilitation Services Administration (Contract No. HEW-105-76-4103), by the Veterans Administration (Contract No. V101(134) P-243), and by a grant from The Arthur Vining Davis Foundations.

* Alan A. Reich served on the Committee until April 1976, and did not participate in the formulation of the recommendations.

**Kenneth A. Klivington, Ph.D., served as Staff Officer to the Committee from January 1975 to January 1976.

VOLUME 1

CONTENTS

PREFACE v

I. FINDINGS AND RECOMMENDATIONS 1

II. REHABILITATION IN OUR SOCIETY 5

The Medical and Social Framework 5
Rehabilitation Medicine 6

Demography 8
Definitions 8
National Demographic Data 10
Sensory (Vision and Hearing) Deficits 13
Vision 13
Hearing 13
Motor (Locomotion and Manipulation) Deficits 14

Organizations and Programs 14

Manpower 16

The Policy Picture 17

The Economics of Rehabilitation, Including Research and Development 20
Cost-Benefit Studies 20
Veterans Administration 21
Rehabilitation Services Administration 22

III. STATE OF THE ART: SCIENCE AND TECHNOLOGY AND THEIR APPLICATION 26

Research and Development 26
Basic versus Applied Research 26
Device Development and Evaluation 28
Device Availability to Users 29

Blindness and Low Vision 31
The Problem and Population 32
Costs of Visual Impairment 32
Aids for Complete or Nearly Complete Blindness 32
Non-Visual Reading Aids 32
Mobility Aids 34
Direct Coupling to the Nervous System 35
Low-Vision Aids 36
Conclusion 37

Hearing and Speech 38
Impairments of Hearing 39
Language 41
Articulation 41
Voice 42
Conclusion 42

Manipulation and Locomotion 43
Deformity 43
The Amputated Limb 43
The Intact Limb 45
Paralysis 45
Skeletal Joint Destruction 46
Conclusion 47

Basic Neuroscience: Regeneration and/or Recovery of Function of the Nervous System 48

REFERENCES CITED IN TEXT 50

GENERAL REFERENCES 55

APPENDIX--Work of the Committee 59

VOLUME 2

CONTENTS

The Limits of Cost-Benefit Analysis as a Guide to Priority-Setting in Rehabilitation. John H. Noble, Jr.	1
The Rehabilitation Program	2
The Cost-Benefit Model	3
Data and Assumptions	4
Sensitivity of the Model	15
Implications and Recommendations	23
References and Notes	29
Public Policy Towards Disability--The Numbers, The Programs, and Some Economic Problems. Monroe Berkowitz	34
Introduction	36
Definition and Concepts	36
Counting the Numbers of Disabled	39
Census Data	40
Age and Disability	40
Age at Onset of Disability	41
Epidemiological Factors and Disability	42
Problems in Counting the Disabled	43
The Workers' Disability Income System - An Introduction	44
Income Restoration	45
Risk Aversion	46
Status	47
Social Insurance	48
Income Support	50
Indemnity Payments	50
Overlapping Categories	51
Other Programs for the Disabled	51
The Workers' Disability Income System - Summary and Conclusions	54
Evaluation	54
Efficiency	55
Equity	55
Effectiveness and Adequacy	56
Some Evaluation Tools	56
Program Evaluation and the Consumer	57
Benefit-Cost Analysis and Social Investment	57
Some Problems in the Application of Benefit-Cost Analysis	58
Political Decision-Making and Benefit-Cost Analysis	59
Benefit and Costs of the Federal-State Vocational Rehabilitation Program	59
Benefits	59

Costs 60
Federal-State Vocational Rehabilitation Program as a Social Investment 60
Conclusions 60
Rehabilitation Trends 62
Public Policy Choices 62
References 64

Social Issues in Rehabilitation. Robert Morris 67

Absence of Comprehensive Aggregate Data - Increases in Prevalence of Disability 68
Neglect of Post-Rehabilitation Situations in Severe Disability 71
Changing Family Capacities 71
Distorting Effects of Severe Disability on Health and Welfare Systems 72
Other Social Dimensions 75
Social Aspects of Short-Term Rehabilitation 76
Suggested Steps 76
References 78

Public Expectations. Albert T. Pimentel 79

Introduction 80
Legislative History 81
Vocational Rehabilitation 81
Education of the Handicapped 82
Other Federal Commitments 84
Role of Consumers 85
Summary of Public Expectations 85
Bibliography 86

Consumer Perspectives. Albert T. Pimentel 87
Additional Reading 93

Critical Issues Facing the Health Care System. Charles C. Edwards 94

Rational Change in the Health Care System 96
Sounding Board -- Form and Function in the Federal Health Effort 101

I. FINDINGS AND RECOMMENDATIONS

The difficulties inherent in bringing the research and development capability of the United States to bear upon the diverse needs of the physically handicapped are highlighted in this report.

Although medical specialties related to rehabilitation have their own associations, there is presently no body of specialists that, together with concerned and informed consumers, has a sufficiently common perception of the problems of the handicapped to be able to suggest common action and priorities. The several departments and agencies of the federal government (or even bureaus and offices of a single department) and the numerous private (or voluntary) agencies are so special-purpose in character as to make it difficult for them to cooperate in a cohesive fashion.

Thus, a multiprofessional mechanism of sufficient quality and visibility is urgently required to assist both the public and private sectors in formulating a strategy that is effective in providing the needed devices and services for the physically handicapped and in aggregating resources and markets to this end.

The Committee, therefore, makes the following recommendations.

1. A Board should be established at the earliest possible time within the framework of the National Research Council (most likely within the Division of Medical Sciences of the Assembly of Life Sciences) in cooperation with the several relevant NRC assemblies and commissions as well as in cooperation with the Institute of Medicine.

This Board should have several functions:

- It should provide a focus for the creation of a community of all the disciplines and groups working with the physically disabled and those concerned with their rehabilitation.
- It should monitor ongoing research and its extension into useful development.
- Soon after its inception, it should study the federal agencies involved with rehabilitation in order to determine the best location for housing of each kind of rehabilitation research.
- It should provide a forum in which the "lead agency" of the federal government (if and when one is selected) could obtain a critical review of its planning and operating procedures.

- It should--in conjunction with the relevant government agencies--establish a coherent and realistic research and development agenda, aid in the establishment of priorities, and serve as a source of advice in the establishment of appropriate peer review panels. It should also systematically review research and development policies and see to it that services and devices are adequately evaluated.

- It should ensure that relevant information is appropriately disseminated and that the physically handicapped are given adequate opportunity (for instance, in specially designed workshops) to examine progress in the field, together with specialists having the requisite technical competence.

- Its national advisory function should include conferences and publications to disseminate (throughout the research community) those basic and applied questions that are central to the restoration of function to the handicapped.

- It should establish programs with other countries for cooperation in rehabilitation research and to share experiences and information so that each nation can benefit by utilizing what is appropriate for its handicapped.

The Committee envisions a Board composed of about two dozen members, of which approximately two-thirds might be identified as specialists in the various disciplines and professions that relate to the physically handicapped and to their rehabilitation. It is expected that roughly one-third of the Board membership be drawn from appropriate representatives of the public interest and from various consumer groups. Thus, it is expected that persons from the following fields would be members of the Board:

Professionals

- Relevant specialties of medicine, such as neurology, ophthalmology, orthopedics, otolaryngology, and rehabilitation medicine; and of engineering, such as electrical, mechanical, biomaterials, and control engineering

- Allied health professions

- Pertinent biomedical sciences, such as neurosciences and fields that relate to disorders of communication and locomotion

- Social and behavioral sciences.

Representatives of the Public Interest

Consumers

- Associations that group the handicapped or disabled
- Industrial and labor organizations concerned with problems of rehabilitation

Liaison should be maintained with such government agencies as the Rehabilitation Services Administration, the Veterans Administration, the Social Security Administration, the Departments of Labor, Defense, Commerce, Transportation and Housing and Urban Development, and professional organizations concerned with the handicapped.

The present research and development effort in the service of the physically handicapped is highly fragmented throughout the federal government and even within the Department of Health, Education, and Welfare (DHEW), a condition that does not lend itself to the development of the required technical competence in the several pertinent fields. The Rehabilitation Services Administration has attempted to take a leadership role, in spite of its highly inadequate resources.

2. It is recommended that the Secretary of DHEW ask the Assistant Secretary for Administration and Management in consultation with the assistant secretaries of Health and of Human Development to determine which organizational arrangement would lead to the necessary strengthening of research and development functions (including a mechanism of peer review) on behalf of the physically handicapped. That arrangement needs to be sensitive to the obligations of service to the handicapped and also needs to be capable of interacting effectively with related efforts in the Veterans Administration, the Social Security Administration, the Departments of Labor, Defense, Commerce, Transportation, Housing and Urban Development; and the various state programs.

3. For major areas of disability a comprehensive national overview should be developed, outlining in full its demography, national cost, and related social and organizational structure.

The collection of demographic data might be coordinated by the National Center for Health Statistics in consultation with the Social Security Administration.

The introduction of technological advances to aid the handicapped usually requires a continuing effort that initially may be close to basic

research and that progressively (in a gradual or stepwise fashion) moves to the stage of practical utilization. For products to aid the handicapped, industrial participation is often not available in the middle stages of product development because of limited market size and high risk of marketing failure.

4. Therefore, it is essential to support research and development efforts at all stages of this process, not only at the two end points. Mechanisms should be investigated which would allow government to participate in the support of middle stages of product development to establish clinical and economic feasibility up to the point where industrial participation can be enticed.

A possible resolution to these problems might be the formation of a private-public corporation charged with the development and market introduction of really promising products.

The intellectual resources and perspective of engineering, the physical sciences, and the behavioral sciences need to be integrated more effectively into biomedical research and development relating to the physically handicapped. Many of the devices and procedures that have potential for alleviation of handicapping conditions require the application of sophisticated engineering principles and techniques as well as awareness of the psychological and social factors that enter into their acceptance.

Care of the disabled in the acute phases of illness must not be separated from rehabilitation. The medical team caring for the patient on an emergency basis must be fully aware of the possible long-term consequences of therapeutic measures intended for short-term goals. This awareness sometimes can be achieved by special centers for particular disabilities or chronic conditions (such as spinal cord injury centers or burn centers), provided these centers are located in medical settings with appropriate back-up facilities. These centers can provide an excellent opportunity for combining research and development with patient care.

II. REHABILITATION IN OUR SOCIETY

THE MEDICAL AND SOCIAL FRAMEWORK

For many years, the emphasis in medicine was on the disease process. By the beginning of the post-World War II era great technological advances especially in the management of infections enabled doctors to treat a number of diseases with gratifying success. The emphasis then advanced to concern with "the patient as a whole." It has now become evident that the social setting in which the patient functions contributes greatly to the patient's total performance.

Rehabilitation is the term used to identify the medical program that encompasses these concepts into a therapeutic whole. It is apparent, then, that the philosophical core of rehabilitation centers around removal of all possible impediments to the disabled individual's ability to live productively and independently. To achieve this goal, it is necessary to integrate restorative and supportive medical health services with psychological, social, and vocational services. A host of other professionals--including basic scientists, orthotist-prosthetists, and biomedical engineers must also be included in this approach. This perspective is distinctly different from traditional medicine's concern with acute, curable diseases.

First, rehabilitation is concerned with chronic disease. To be maximally effective, however, the rehabilitation process must start during the acute stage of the disease or injury. In hemiplegia or traumatic paraplegia, for instance, rehabilitation techniques added to the acute care program include range of motion to prevent limitation of movement, active exercises of the paretic muscles to maintain their strength, and splinting of paralyzed joints to avoid deformation.

Second, rehabilitation is concerned with disability: Medical management, restorative processes, and reconstructive surgery are designed to minimize residua and maximize functional capacity. When functional recovery is impossible, substitutive devices are a prime requirement.

Third, because the problems encountered are frequently multifaceted, the therapeutic program must be organized in a comprehensive, multidisciplinary manner.

Fourth, physicians are sometimes not involved directly with many patients in major areas of handicap such as blindness and deafness. For these, rehabilitation depends primarily on other specialists such as orientation and mobility trainers, audiologists, and hand- and lip-reading instructors.

Fifth, biosocial factors--social, psychological, economic, and vocational--are of considerable importance as part of the commitment to restore

the disabled to their own family units as well as to the community as functionally adequate members of each.

Biosocial factors are discussed in greater detail in the papers in Volume 2 of this report.

Rehabilitation Medicine

Medical practice and social mores have significant impact on the delivery of rehabilitation services. The objective of traditional medicine is to restore the patient to his usual functional level; the goal of rehabilitation medicine is to obtain maximal function within the restrictions of the patient's permanent loss. These two program can be blended into "degrees of restoration." Such a blending of purposes also helps the physician to avoid viewing the patient as incurable. The medical profession, however, has traditionally been interested primarily in detecting and curing disease. The emphasis on care of patients with acute needs has been pervasive. Chronic disease is all too often perceived as a series of acute episodes. Attention and interest are centered on the most dramatic events that compel the patient to seek new treatments. Designing these treatments calls upon skills that practitioners recognize as legitimate and rewarding to exercise. Nonetheless many medical specialists, such as cardiologists, rheumatologists, and pulmonologists, must practice rehabilitation medicine routinely. Unfortunately, however, rehabilitation medicine is not stressed, and often not even mentioned in many medical school curricula. The importance of rehabilitation medicine in the training and practice of all physicians should be recognized.

Rehabilitation medicine as a distinct entity dates back to 1948, when the Specialty Boards in Rehabilitation Medicine were first organized with about 400 physician specialists. By 1971, the number of physicians in rehabilitation medicine approached 1,500, a growth almost solely attributable to funding from federal sources through the Rehabilitation Services Administration and its predecessor agencies. Even so, in that year, the almost 1,500 rehabilitation medicine physicians constituted only 0.44 percent of the 334,000 physicians in the United States. With roughly a 10 percent incidence of disability and chronic disease in the country's total population, only a small fraction of the physiatric needs can be satisfied (see Manpower). One explanation for this shortage is the low prestige of rehabilitation medicine in comparison with other medical specialties.* In fact, the field does not even enjoy departmental status in some notable medical schools.

Rehabilitation deals with the chronic aspects of chronic disease. When the acute episodes have passed, or in the long periods between them, the patient needs to lead as normal a life as possible. He will want to

*Pertinent to this view is the fact that in the United States in 1974-1975, 221 of the 331 (66.8%) of residents in physical medicine and rehabilitation were foreign medical graduates, compared to 104 of 1,226 (8.5%) for ophthalmology and 230 of 1,749 (13.2%) for orthopedic surgery (2).

function as a member of society, not as an isolated organism. The damage caused by the disease must therefore be viewed in the context of the patient's life-style and daily activities. What functions or tasks are to be performed will depend on the family and on the community setting in which the patient lives. Failure to anticipate these needs will frequently create serious or insurmountable difficulties for the patient.

The primary consideration of rehabilitation medicine is that the medical team caring for the patient during the acute phase of an illness be aware of any possible long-range consequences of therapeutic measures used to achieve short-range goals. The ultimate rehabilitation of a patient is especially dependent on the care given at this time. Prolonged bed rest or immobilization may sometimes seem to be good, conservative therapy, especially in complex situations where diagnostic and therapeutic decisions are difficult. But the patient may pay a heavy price for unnecessary inactivity. Contractures, pressure sores, and excessive muscular weakness need not be the inevitable consequences of such an initial insult, but they are often the penalty for acute care that is not oriented toward the rehabilitation process.

Limitation of joint motion and contractures can restrict or completely preclude effective rehabilitation. Frequent physical therapy can prevent this complication. Once deformed, however, the joint may never return to normal, permanently limiting the patient's capabilities. A medical staff not familiar with this point of view may not start proper therapy soon enough in the post-injury period for fear of harming the patient.

Spinal cord injuries are also frequent causes of such problems. Errors in management due to lack of experience or familiarity in the first days, hours, or minutes after an injury can lead to problems that require months to resolve. Spinal instability as the result of ill-advised or improperly performed surgical procedures may require months of bed rest and possibly additional surgery to stabilize the spine.

A single pressure sore will, on the average, require three months to heal before effective rehabilitation can begin. Pressure sores are prevented by regular turning and by good nursing care. This requires specially trained nurses who are alert to the problem, and may require special equipment.

The urological management of the patient with an injured spinal cord is of paramount importance to his long-term survival and well-being. The seeds of destruction are sown through the indwelling catheter in his early care. It has been conclusively shown that intermittent catheterization will consistently result in sterile urine and effective bladder retraining. To be most effective the procedure should be started within two or three days following injury. This technique, however, requires a trained staff, and is beyond the capability of the average hospital. Pressure sores caused by the catheters are particularly difficult problems to treat and may prevent effective bladder rehabilitation. Proper urological management started

in the first days after injury results in catheter-free patients with sterile urine in eighty to ninety percent of such cases (3).

The psychological effect of spinal cord injury can be devastating. This may be compounded by ill-advised and inappropriate counseling of the patient and his family in the first days following injury by persons unfamiliar with the full ramifications of the problem. To tell a complete quadriplegic that he will walk out of the hospital or an incomplete paraplegic that he will never walk again are equally false and destructive to long-term rehabilitation.

In the medical care system there are many places where ignorance of the patient's ultimate rehabilitation needs can lead to a final result that is less satisfactory than it might have been. For example, if ambulance attendants are trained to apply protective collars in cases of possible cervical spinal injury the damage from such injuries would be significantly reduced. Orthopedists, neurologists, neurosurgeons, and other medical specialists must assign higher priorities to those aspects of their treatments that affect the rehabilitative prognosis.

One mechanism for accomplishing exchange of information between those who give acute care and those who provide rehabilitation care is the specialized center. Such centers are devoted to a particular disability or chronic disease, and can only function well in an appropriate medical setting. Burn centers, spinal cord injury centers, stroke centers, trauma centers, and cardiac centers can be settings in which patients receive their best chances for successful outcomes, and in which the medical care team has its best opportunity to share learning and experience. Specialized centers also provide an excellent opportunity for combining research and development with patient care.

DEMOGRAPHY

Definitions

A review of current literature quickly reveals overlapping and confusing uses of the terms "handicap," "disability," and "impairment." Because the government plays a key role in rehabilitation, the definitions annotated by Lawrence Haber of the Social Security Administration (SSA) (4) and reviewed within the setting of statutory and regulatory usage are the most pertinent to this report although it deals only with physical handicap.

The Rehabilitation Act of 1973* contains these definitions:

- The term "handicapped individual" means any individual who (A) has a physical or mental disability which for such individual constitutes or results in a substantial handicap

*Public Law 93-112, 93rd Congress, H.R. 8070, September 26, 1973.

to employment and (B) can reasonably be expected to benefit in terms of employability from vocational rehabilitation services...

- Physical or mental disability means a physical or mental condition which materially limits, contributes to limiting or, if not corrected, will probably result in limiting an individual's activities or functioning.

The Social Security Act contains these definitions:

- The term "disability" means (A) inability to engage in any substantial gainful activity by reason of any medically determinable physical or mental impairment which can be expected to last for a continuous period of not less then 12 months; or (B) in the case of an individual who has attained the age of 55 and is blind (within the meaning of 'blindness' as defined in section 416(I) (1) of this title), inability by reason of such blindness to engage in substantial gainful activity requiring skills or abilities comparable to those of any gainful activity in which he has previously engaged with some regularity and over a substantial period of time.

- A "physical or mental impairment" is an impairment that results from anatomical, physiological, or psychological abnormalities which are demonstrable by medically acceptable clinical and laboratory diagnostic techniques.

- A physical or mental impairment is an impairment that results from anatomical, physiological, or psychological abnormalities which are demonstrable by medically acceptable clinical and laboratory diagnostic techniques. Statements of the applicants (including his own description of his impairment symptoms) are, alone, insufficient to establish the presence of a physical or mental impairment.

The Office of Education* uses these definitions:

- "Handicapped persons" means mentally retarded, hard of hearing, deaf, speech impaired, visually handicapped, seriously emotionally disturbed, crippled, or other health impaired persons who by reason of their handicapping conditions cannot succeed in a vocational or consumer and homemaking education program.

- "Handicapped children" means mentally retarded, hard of hearing, deaf, speech impaired, visually handicapped, seriously emotionally disturbed, crippled or other health

*Department of Health, Education, and Welfare, Office of Education.

> impaired children who by reason thereof require special education and related services. The term includes children with specific learning disabilities to the extent that such children are health impaired children who by reason thereof require special education and related services.

In summary, "impairment" denotes an altered physiological or anatomical status. The cause of the body's altered function may be genetic (cystic fibrosis), congenital (spina bifida), traumatic (spinal cord injury), or infectious (poliomyelitis). "Disability" differs from impairment by being defined in behavioral and social terms; i.e., an impairment-related inability to perform normally in socially defined role functions (such as vocational or educational activities, self-care, mobility, or communication). "Handicap" refers to a type of disability in which physical or social environmental factors contribute to the deficient role performance.

National Demographic Data

The myths of Americans as a healthy, active people and of medical science as curative are sorely tested by the scale and scope of disability and handicapping conditions in the United States reported in various surveys. Accurate numbers are difficult to cite. All data collected thus far by either government or private organizations have been on a fragmentary basis. The definitions cited above are not used consistently. The terms "disease," "disability," and "handicapping" conditions are commonly interchanged. The foci of the studies vary. Some follow medical etiologies, while others are generally concerned with functional limitations. Neither approach is complete and generally the criteria vary widely. The Veterans Administration represents an independent, vertically integrated health-care system separate from civilian medicine. As such its data tend to be overlooked in most surveys.

Estimates of elderly and non-elderly handicapped persons in the United States compiled by the Urban Mass Transportation Administration (UMTA) of the Department of Transportation (5) encompass about 6 percent of the U.S. population. These estimates are summarized in Table 1.

Knowledge of the major causes of disability would aid in evaluation of national needs of the handicapped and in planning ways to prevent disability. The National Center for Health Statistics estimates that 24.6 percent of all impairments are due to injury. In 1971, about 25.4 percent of injuries occurred in the home, 29.3 percent at work, and 17.8 percent in moving motor vehicles (6). This last percentage, occurring in moving motor vehicles, is increasing.

What is significant is not the exact number of disabled but the fact that the numbers are so large and are increasing. Better control of infectious diseases, such as poliomyelitis or congenitally acquired rubella, has prevented some disabilities. The total number of handicapped persons, however, continues to increase because today severely injured people are

TABLE 1

Urban Mass Transportation Administration Estimate of Handicapped Persons[a]

Handicapped Classs	Elderly Handicapped	Non-Elderly Handicapped	Total Handicapped
Visual impairment	1,430,000	540,000	1,970,000
Hearing impairment	160,000	190,000	350,000
Wheelchair	230,000	200,000	430,000
Walker	350,000	60,000	410,000
Other special aids	2,280,000	3,210,000	5,490,000
Other mobility limitations	1,510,000	1,800,000	3,310,000
Temporary acute conditions	100,000	370,000	470,000
Institutionalized	930,000	30,000	960,000
Total	6,990,000	6,400,000	13,390,000

[a] Data from Urban Mass Transportation Administration of the Department of Transportation (5).

less likely to die, formerly fatal diseases may be arrested, and terminal conditions may be prolonged.

The wide discrepancies in estimates of the disabled derive in part from paucity and lack of rigor in primary demographic data collection, as well as from the problem of translating primary medical data into its functional consequences.

Emphasis on acute care contributes to the poor quality of primary data on the medical etiologies of what become disabling and handicapping conditions. Life-threatening acute episodes receive the most attention and thereby probably produce the best data. The relationship of these intense episodes to chronic or permanent disablement is not compatible with the usual hospital-based data collection system. For example, each hospitalization by a diabetic, nephrotic, or arthritic patient is treated as an acute event--although it is only one of many that a patient with a chronic condition will experience over a lifetime of functional limitation. In the statistics, however, this repetitive experience of one individual is more likely to appear as a sum of acute episodes than as a continuous history of disablement.

Most published data on the handicapped are derived from health surveys, conducted periodically by the National Center for Health Statistics, the Social Security Administration and other organizations using interview techniques with statistical samples of the noninstitutional population. Those patients whose chronic illness is extremely severe or whose family resources are limited must reside for long periods in an institutional setting. In 1967, one-sixth of all institutionalized individuals (648,000) were in chronic disease facilities for physical disabilities, with the remaining five-sixths institutionalized for psychiatric problems (7).

One final example of fragmentation and irrational duplication in demographic data collection relates to the traumatic spinal cord injury. This is a well-defined insult with clear symptoms producing overwhelming human and economic consequences in terms of immobility and long-term care. Given the relatively small numbers of such injuries, the usually dramatic circumstances in which they occur, and their huge medical, social, and financial cost, one would assume that nationwide, high-confidence-level data would be available. On the contrary, valid national estimates of the numbers of spinal cord injury do not exist at present. Although ten studies have been financed by state and federal agencies and foundations since 1970, they have been restricted to individual states or limited geographical regions. Now two national spinal-cord registries are under way, but neither includes data from the Veterans Administration which, with its sixteen Spinal-Cord Injury Services, represents by far the largest organized spinal-cord treatment system in the United States.

The following statistics are presented with these caveats in mind.

Sensory (Vision and Hearing) Deficits

Vision. The most rigorous data have been those of the Model Reporting Area (MRA). Extrapolating from a 14-state statistical base to the nation, they estimate that 290,000 persons are legally blind--that is, they have visual acuity of less than 20/200 in the better eye using the best optical correction (8). However, the statistics most commonly accepted have been those of the National Society for the Prevention of Blindness, which estimated the total number of cases of legal blindness in the United States as 437,000 in 1970. Using a functional criterion, the National Health Survey estimated that, in 1965, approximately 1.2 million persons could not read ordinary newsprint while wearing glasses (9).

Although the administrative definition of legal blindness refers to "best correction," few people probably have best correction; in fact, they may not even have good correction. Better eyeglasses or lens-type devices, as well as training in efficient use of impaired vision, may remove a significant number of individuals from the category of those severely visually impaired.

As for other handicapping conditions, estimates of the visually impaired vary widely because different definitions of visual impairment are used.

Hearing. Hearing impairment is the single most prevalent chronic physical disability in the United States. The National Census of the Deaf Population estimates that 13.2 million persons suffer a bilateral loss of hearing that significantly interferes with their ability to understand speech. This same census estimates that 0.5 million are profoundly deaf, with 400,000 of those becoming deaf before the age of nineteen (9, 10). The National Health Survey (11) estimated that in 1967 six percent of the population had a significant bilateral hearing impairment; of these, 80 percent were forty-five years old or more and 55 percent sixty-five years old or more.

The critical role of hearing in the development of language and the production of speech is well established, but unfortunately there are virtually no data on very young and school-age children with hearing losses. In the 1968-1969 school year, one-half of the estimated fifty thousand hearing impaired children enrolled in special education programs in the United States were surveyed. Seventy-four percent of these have been deaf from birth. The onset of deafness was placed at under three years of age for 17 percent of these, and for the remainder, at three years of age or later (12).

Available data on the hearing-impaired population of the United States have neither the scope nor the detail of data on the visually impaired. The U.S. Bureau of the Census asks about blindness in each census; it has not counted deaf people since 1930. The Internal Revenue Service provides a deduction for blindness but not for deafness. Audiometric measurement is neither as simple nor as routine as the Snellen eye chart (despite its inadequacies); it is certain therefore, that a more thorough measurement of audition throughout the population would generate even more discouraging statistics on hearing loss. Even for those people who know they have hearing

troubles, rehabilitation has been incomplete, inadequate, or impossible (rehabilitation may not be possible via a hearing aid because, for example, of recruitment or nerve deafness).

Motor (Locomotion and Manipulation) Deficits

Statistical information on neuromuscular-skeletal dysfunctions is very difficult to interpret because of the great diversity of causes and range of such disabilities.

Causes of neuromuscular dysfunctions include birth defects (e.g., cerebral palsy, spina bifida), genetic diseases (e.g., muscular dystrophy, osteogenesis imperfecta), and other chronic and/or degenerative diseases (such as Parkinsons disease, multiple sclerosis, or disabling arthritis). Approximately 4 million people affected by these conditions in the United States are limited in activity and mobility (13, 14, 15).

About 5 million people are estimated to have amputation, limb or spinal deformity also limiting activity and/or mobility, and requiring orthoses (16, 17). An additional million are limited in locomotion and manipulation by paralysis or paresis of one or more limbs (14, 18, and National Center for Health Statistics, unpublished figures). As discussed earlier in this section, these figures are very inaccurate but are indisputably large.

ORGANIZATIONS AND PROGRAMS

The societal response to the obvious needs of disabled persons has been the creation of a large number of organizations, roughly corresponding to the variety of handicapping conditions, with much overlap, frequent competition, and gaps.* For example, the Directory of Organizations Interested in the Handicapped, 1976, identified 225 organizations in an admittedly incomplete list.

The most definitive work in blindness is a report to the Subcommittee on Rehabilitation of the National Institute of Neurological Diseases and Blindness, June 1968 (8). This work provides a comprehensive national overview of a rehabilitation "system"--in this case, for blindness and low vision. It presents in one document the total picture of demography, national cost, social and organizational problems, interinstitutional rivalry, and public lethargy. The report also suggests a range of proposed directions for change and the constraints thereon (including research and service considerations). Similar reports need to be generated for other physical handicaps.

*In 1969, Scott reported that over 800 organizations existed dealing with the blind. However, he concluded that organizations for the blind failed to help blind people effectively (19).

The mosaic character of organizations for the handicapped is mimicked in federal agencies and programs. The Office for Handicapped Individuals (OHI) was established in the Office of the Assistant Secretary for Human Development of the Department of Health, Education, and Welfare in 1974, as a "coordinating and advocacy unit for its target population." It published a list of 103 federal assistance programs that "provide assistance to the handicapped and/or people working with or for them."(1) The Department of Health, Education, and Welfare is responsible for fifty-three programs in the Public Health Service, the Office of Education, the Office of Human Development, the Office of the Secretary, the Social Rehabilitation Services, and the Social Security Administration. The Veterans Administration is represented by twenty-three programs in the Departments of Medicine, Surgery, and Veterans Benefits. In addition to these two obvious executive departments, programs serving the handicapped are also found in the Departments of Agriculture, Defense, Housing and Urban Development, Interior, Labor, and Transportation, as well as the Civil Service Commission, the General Services Administration, the Library of Congress, the National Aeronautics and Space Administration, the President's Committee on Employment of the Handicapped, the Small Business Administration, Action, and the Committee for the Purchase from the Blind and Other Severely Handicapped.

Perhaps coordination of these many programs will be improved in time through the existence of the OHI. The functions of this office are:

> To serve as the focal point in the Department (DHEW) for the consideration of issues and policies affecting the handicapped and development of departmental goals for handicapped programs.
>
> To analyze program operations on a continuing basis to evaluate the effectiveness of all programs providing services to handicapped individuals.
>
> To develop means of promoting the prompt use of engineering and other scientific research to assist in solving problems in education, health, housing, rehabilitation, architectural and transportation barriers, and other pertinent areas.
>
> To provide a central clearing house for information and referral. This includes referral to existing information sources in the handicapped field within the Department of Health, Education, and Welfare, other departments and agencies of the Federal government, and public and private agencies and organizations which operate on a National level (1).

Thus far, OHI has been limited in its coordinating and advising functions by a low budget ($600,000 for FY 1977). See Table 3.

MANPOWER

The growth of manpower in any field is inextricably linked to the training process. Some progress has been made primarily through the system of National Rehabilitation Research and Training Centers supported by the Rehabilitation Services Administration.

The range of medical and allied health professional skills that are needed by the individual patient over the lengthy period of rehabilitation mandates an integrated and interdisciplinary approach, effectively utilizing the skills of physicians from all specialties, engineers, physical and occupational therapists, clinical psychologists, speech pathologists, rehabilitation counselors, and others.

One means of attracting physicians to the practice of rehabilitation is to relieve them of all activities which do not require their specialized skills. This goal can be accomplished by vigorous development of the allied health professions. Such professionals can provide all the therapeutic maneuvers to develop function exclusive of surgical reconstruction and medicinal management. If allied health professionals are encouraged to advance their skills in evaluation and program planning, and to develop a scientific base for their actions, patient care will improve and the physician will not be obligated to perform tasks which do not challenge his professional areas of competency or interest. Once these distractive responsibilities are eliminated, physicians of all specialties can be interested in directing their skills towards the betterment of even the permanently disabled patient.

Over the period of 1950-1969 significant increases (20, 21, 22) in numbers of allied health professionals occurred: physical therapists from 4,600 to 14,500, occupational therapists from 2,000 to 7,000, and speech pathologists and audiologists from 1,800 to 18,000. There was almost a tenfold increase in the number of rehabilitation/vocational counselors from 1,500 to 12,000 (of which 5,000 are in state agencies).

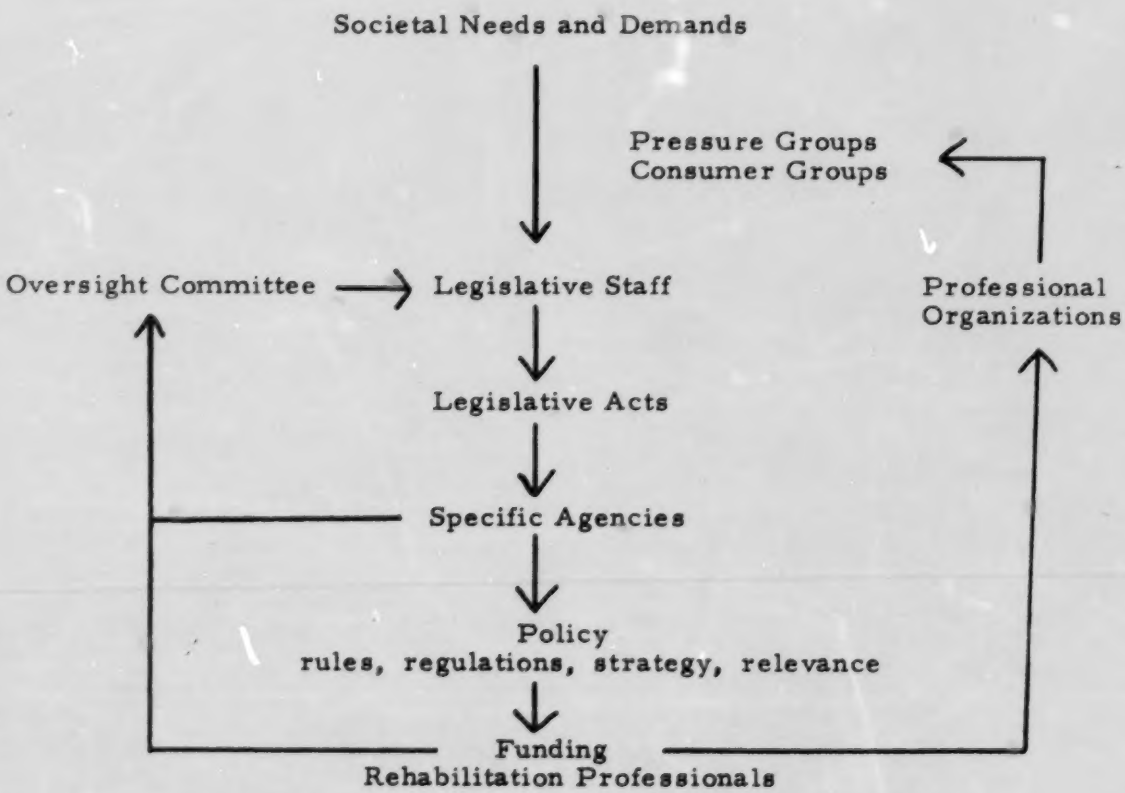
In spite of the increased need, since 1969 allied health professionals have been consistently in low supply. In projecting the requirements of 1980, the limiting factor for obtaining sufficient numbers of physical therapists and occupational therapists is lack of training facilities. Unless training programs can be expanded, the shortage of personnel in rehabilitation-related allied health fields will not be relieved (23).

The various engineering specialists so far have no formal status in rehabilitation. The only identifiable groups of practicing engineers in rehabilitation are in the Veterans Administration and in the Rehabilitation Services Administration's Rehabilitation Engineering Centers. Formal training procedures for rehabilitation engineers do not exist yet.

THE POLICY PICTURE*

Rehabilitation deals with severe, chronic, even catastrophic disease states--often compounded by a background of traumatic events. The need for expensive long-term health care and the psychosocial economic and vocational effects of these diseases have necessitated pervasive government intervention on administrative as well as professional levels.

As schematized in the diagram below, translation of societal needs and demands of the physically disabled into government action involves the influence of legislative consumer and pressure groups, as well as professional organizations and oversight committees, on legislative staff. Staff response, through the enactment of legislation and establishment of specific agencies, ultimately results in actual policy with funding for rehabilitation professionals and programs.



*Public Policy Towards Disability is discussed in the supporting paper by Monroe Berkowitz in Volume 2 of this report.

The history of rehabilitation legislation is briefly reviewed below,* commencing with the Vocational Rehabilitation Act of 1920, which originated as the National Civilian Vocational Rehabilitation Act (PL 66-236). This Act provided a program of rehabilitation for disabled civilians and was limited to vocational guidance, training, occupational adjustment, prosthetics, and placement services. Its provisions were not drastically changed until 1943, when PL 78-113 broadened the concept of vocational rehabilitation to include "any services necessary to render a disabled individual fit to engage in remunerative occupations." For the first time, surgical services to eliminate or reduce an individual's disability and services for the mentally retarded were authorized.** In 1954 (PL 83-565), research provisions were added for the first time. PL 89-333, enacted in 1965, provided for additions to the program such as construction of new rehabilitation facilities, workshops for the handicapped, and elimination of financial need as a requirement for obtaining rehabilitation services.

The Rehabilitation Act of 1973 (PL 93-112) was enacted "to replace the Vocational Rehabilitation Act, to extend and revise the authorization of grants to states for vocational rehabilitation services, with special emphasis on services to those with the most severe handicaps, to expand special federal responsibilities and research and training programs with respect to handicapped individuals..."

Current amendments to the Rehabilitation Act (1973) provide for formulae grants-in-aid to states to assist them in rehabilitating handicapped individuals

> so that they may prepare for and engage in gainful employment to the extent of their capabilities, thereby increasing not only their social and economic well being but also the productive capacity of the nation.

In addition, each state receives an allotment for innovative Vocational Rehabilitation Services that (a) initiate or expand such services to the most severely handicapped, or (b) start special programs to initiate or expand services to classes of handicapped individuals who have unusual and difficult problems in connection with their rehabilitation--particularly handicapped individuals who are poor and whose treatment, education, and rehabilitation responsibilities are shared by the state agency with other agencies.

Section 202(a) of the Rehabilitation Act also provides for federal grants and contracts for "research, demonstrations, and related activities which bear directly on the development of methods, procedures, and devices to assist the provision of vocational rehabilitation services to handicapped individuals."

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* For a complementary discussion, including education legislation, see the supporting papers by A. Pimentel "Public Expectations", and "Consumer Perspectives", Volume 2 of this report.

**Mental handicaps per se are not covered in this report.

Additionally, the Act provides for the establishment and support of rehabilitation research and training centers, rehabilitation engineering research centers, and a program for spinal cord injury research and end-stage renal disease research.

A workable scientific peer review system (using the National Institutes of Health as a model) had existed in the Rehabilitation Services Administration until 1973, when it was unfortunately abruptly disbanded by the Secretary of Health, Education, and Welfare. In 1974 Public Law 93-112 reestablished a scientific and technical peer review mechanism providing for technical review of applications by a group of experts in an appropriate field of rehabilitation, who are not federal employees. In the final regulations published in the Federal Register (24), it was provided that peer review be conducted in group meetings of experts and that an advisory group be established, with responsibilities including review of short-term and long-term plans affecting rehabilitation research. In summary, the provisions called for establishment of the equivalent of study sections and general advisory groups, but no fiscal appropriations were made for these purposes. The study section model is yet to be reestablished although a new review pathway is being considered: peer review under a contractual agreement with an external agency. The restoration of a peer review procedure modeled after that of the NIH, with study sections and an advisory council composed of professionals with a background in rehabilitation medicine, as well as representatives of pertinent specialties such as bioengineering, neurology, neurosurgery, ophthalmology, orthopedics, speech and hearing, etc., would seem the preferable alternative even if this approach requires reallocation of some available funds.

It is apparent that the laws that have been enacted have begun to comprise the core of a viable research and technological program in rehabilitation. It is equally apparent that the positive impact of the legislation reflects, in the main, the viewpoints of scientific professionals and their organizations, the views and interests of handicapped consumers, and the moderating activities of congressional oversight committees. In spite of the accomplishments that have been achieved as a result of informal communications between the scientific community and agency personnel, the system has not worked well because of a lack of scientific leadership and advocacy and a lack of sufficiently organized and knowledgeable scientific staff.

Until recent years legislative emphasis has been almost exclusively directed to the support of a handicapped population with some degree of demonstrable vocational potential. This stricture has undoubtedly excluded a large group of handicapped persons who lack such potential. The Rehabilitation Act of 1973 (PL 93-112) recognized this void and provided $1 million for a special study to demonstrate the feasibility of rehabilitation of those handicapped so severely that they cannot return to gainful employment and would otherwise be ineligible for rehabilitative assistance. This small appropriation is for limited exploration of a seriously deficient area in the delivery of comprehensive health care services.

Consumer involvement in the formulation of rehabilitation policy and in the design and delivery of services is slowly increasing.* This involvement is mandated by federal employment practices and may be expected to help increase the handicapped community's awareness of rehabilitation research. The scientific community may then, in turn, become more aware of service delivery needs and new policy formulations may relate those needs with research more closely.

No system exists to ensure communications between the scientific and handicapped communities. Because the goals of research are usually expressed in technical rather than in human terms, their practical implications for rehabilitation are often too obscure to seem significant to the handicapped.

The Swedish Institute for the Handicapped (25) involves both the research and the handicapped communities in common efforts ranging from agenda generation to evaluation of devices and procedures. This is a pertinent model that could not be taken over as such but would need to be adapted to American realities.

THE ECONOMICS OF REHABILITATION, INCLUDING RESEARCH AND DEVELOPMENT

The economics of rehabilitation and physical disability defy simple or quick analysis. Questions of cost to society are inextricably intertwined with questions of the types of services to be considered. The problem is further complicated by overlapping services and by the paucity of demographic data on the populations of handicapped served.

Cost-Benefit Studies

Cost-benefit studies of rehabilitation efforts have been very difficult to conduct, partly because nonmonetary "human" benefits of such efforts are hard to quantify. The limits of cost-benefit analysis and the relationship of this type of analysis to setting priorities in rehabilitation of the handicapped are discussed by John H. Noble, Jr., Director of Research and Policy Analysis for Social Services/Human Development, Department of Health, Education, and Welfare, in Volume 2 of this report.

Further, the Rutgers Bureau of Economic Research has been conducting research for several years on economic issues of the handicapped. This topic is discussed comprehensively by Monroe Berkowitz, Director of the Disability and Health Economics Research Section, Rutgers University, in Volume 2 of this report.

*"Public Expectations" and "Consumer Perspectives" are discussed more fully in the supporting papers by Albert Pimentel in Volume 2 of this report.

The total financial burden of physical disability is difficult to estimate, especially for such indirect costs as lost employment and premature death. The expenditures for one handicap area, blindness (from income maintenance to prevention and research) were analyzed in a report, Blindness and Services to the Blind in the United States (8). According to this report, even in the FY 1967, the estimated total cost for services to the blind was almost $470 million.

A study by Cooper and Rice (26) (Office of Research and Statistics of the Social Security Administration) does not specifically identify the physically handicapped. Some estimates can be made, however, when it is recognized that physical handicaps fall predominantly into the category of diseases of the nervous system and connective tissue. For 1972, estimated direct costs in these two categories--for prevention, detection, treatment, rehabilitation, research, training, and capital investment in medical facilities were $9.6 billion. When indirect costs such as lost employment and premature death were added, the staggering total of nearly $20 billion dollars was reached.* This amount is approximately 10 percent of the total economic cost of illness as reported in this paper. Whatever fraction of this total is related to physical handicap remains difficult to estimate.

In spite of the difficulties of cost-benefit analysis acknowledged above, the magnitude of the expenditures cited in both this report and in the Rutgers study is indeed impressive.

In rounded figures, the total federal health expenditures for research in FY 1975 was 2.5 billion dollars. Total federal health expenditures for the same year were $36.8 billion,** a ratio of federal research to federal health expenditures of 7% (27). Most of this money was spent by the Department of Health, Education, and Welfare, but the Department of Defense, the Veterans Administration, and other federal agencies also expended funds for health. As shown in Table 2, in FY 1975 the Rehabilitation Services Administration spent $19.9 million for rehabilitation research, only 0.8% of the national research budget (28). This seems a disproportionately low figure for an area of such magnitude in both numbers of afflicted and total costs.

Veterans Administration

The Veterans Administration is the largest health care system in the nation, with over $5.4 billion in pensions and other compensation going to about 4.7 million veterans. It operates 165 hospitals with

* The cost of pain and suffering is omitted because it cannot be quantified, but the fact that some diseases (such as cancer) cause much pain is undoubtedly reflected in the allocation of resources.

**The total national expenditures for health in the same year were $118.5 billion, accounting for 8.3% of the gross national product.

approximately 90,000 beds, and employs 150,000 health care professionals, among whom are 118 full-time neurologists. There are an estimated 28 million veterans over 40 years of age to whom the system is obligated to provide health care should the need arise.

In 1945, the Veterans Administration was authorized to provide prosthetic appliances for the handicapped. In 1948, it was further authorized (PL 80-729) to spend $1 million per year in research on prosthetic appliances and sensory aids.* The fiscal ceiling of $1 million has since been removed. In FY 1970, the prosthetic appliance service program cost $20 million with an additional expenditure of $1.6 million for prosthetics research. Inevitably, these costs will continue to rise.

The Veterans Administration's vocational rehabilitation program was studied recently by Sars Levitan (30). This program is unique because rehabilitation is a mandated right of the eligible veteran without any need to establish vocational potential. Compensation awards are made by a VA board and cover injury, disease, or accident. In 1974 there were 2.2 million recipients who received compensation benefits. In 1976 benefits ranged from $35 to $1,655 per month, depending on the degree of disability. All veterans who receive disability compensation are eligible for rehabilitation services (consisting mainly of vocational aid) since physical restoration is part of the guaranteed medical services to disabled veterans. The total costs of veteran vocational rehabilitation are not known because costs of medical restoration are not separated from regular medical care, and the manpower program expenditures are not available. It has been estimated that total costs per patient for training, medical treatment and other assistance exceeded $5,000 in veterans vocational rehabilitation compared with the average outlay of $800 per person under the federal/state program. The Veterans Administration experience with offering expensive and extensive services to a relatively employable segment of the disabled population has not been unqualifiedly successful. The unemployment rate was still relatively high (13-22%) among those with 60% or higher disability. Levitan concludes however, that education rather than disability status seemed to have the most effect on employment success. Therefore, in planning rehabilitation programs, emphasis on college education appears warranted.

Rehabilitation Services Administration

The prime function of the Rehabilitation Services Administration, as defined in the Rehabilitation Act of 1973 (Public Law 93-112), is to provide vocational rehabilitation services through the individual states. Of the total budget of the Rehabilitation Services Administration (approximately $750 million), about 3 percent is devoted to medical rehabilitation research, including applications of technology.

* A National Research Council, Assembly of Life Sciences Committee on Prosthetics Research in the VA completed a review of VA programs in prosthetics research in September of 1976 (29).

Research and training expenditures by the Rehabilitation Services Administration since 1970 are presented in Table 2. The table reveals a severe shrinkage of available funds, already much depleted by inflation. The approximate total amount of $20.0 million was increased by $4.0 million through a release of funds by the Office of Management and Budget in 1976. Table 3 shows the projected appropriation levels for the Rehabilitation Services Administration for FYs 1977 and 1978. While there is authorization in the Rehabilitation Act Extension of 1976* (31) for $30 million for fiscal 1977 and 1978 for research, it has already been announced that the actual administrative budgetary recommendation for this item was reduced to $18 million. Thus the trend continues to be one of decreasing support for research by the Rehabilitation Services Administration.

Approximately $5 million, less than 1 percent of the Rehabilitation Services Administration budget, has been devoted in recent years to rehabilitation engineering or to the application of technology in rehabilitation. It is clear, therefore, that the primary management resources of the Rehabilitation Services Administration must be directed to its major task of providing vocational services and evaluating the effectiveness of those services. Its leadership staff cannot be expected to be deeply concerned with research in rehabilitation medicine, particularly with the application of technology.

The potential benefit to millions of disabled persons through the application of technology remains largely unrealized. The present arrangement is not adequately responsive to the health and functional needs of disabled persons.** The question of what organizational arrangement within DHEW would lead to the necessary strengthening of the research and development functions on behalf of the physically handicapped is one of utmost significance and urgency.

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* Public Law 94-230, 94th Congress, H.R. 11045, March 15, 1976.

**How the problems of the handicapped relate to criltical issues facing the health care system is discussed by Charles Edwards in his supporting paper in Volume 2 of this report.

TABLE 2

Rehabilitation Services Administration Research and Training Expenditures Since 1970[a]

Research (Title II of PL 93-112)	Expenditures (x $1,000) 1970	1971	1972	1973	1974	1975	1976
Project research grants[b]	20,003	20,955	19,255	9,505	9,755	3,000	5,059
Research and training centers	9,761	10,275	11,811	10,341	10,341	10,341	11,341[c]
Regional research institutes	-	405	500	500	500	500	500
Spinal cord injury centers	-	-	-	-	-	2,100	2,100
Rehabilitation engineering centers	-	-	-	-	-	4,000	5,000
Total research	29,764	31,635	31,696	20,446	20,596	19,941	24,000

24

[a]Data from RSA Office of Research, August 25, 1976.

[b]For 1970-1972, project research grants include funds for spinal cord injury and rehabilitation engineering centers.

[c]Included $1,000[2] for rehabilitation engineering at rehabilitation and training centers.

TABLE 3

Projected Appropriations for the
Rehabilitation Services Administration

	Expenditures	
	FY 1977	FY 1978
Basic state grants	$740,000,000	$760,000,000
Innovation and expansion grants	25,000,000	25,000,000
Client assistant projects[a]	2,500,000	2,500,000
Research	30,000,000	30,000,000
Training	25,000,000	30,000,000
Construction of facilities	such sums[b]	such sums[b]
Training services and facility improvement grants	such sums[b]	such sums[b]
Office for handicapped individuals	600,000	600,000
Architectural and transportation barriers compliance board	1,500,000	1,500,000

[a]Authorizations provide for a level of up to $2,500,000 but not less than $1,000,000 for fiscal years 1977 and 1978

[b]"such sums" indicates that there is no limitation on the amount of appropriation by Congress: "such sums as may be necessary."

Source: P.L. 94-230 Rehabilitation Act Extension of 1976.
94th Congress, H.R. 11045, March 15, 1976.

III. STATE OF THE ART: SCIENCE AND TECHNOLOGY AND THEIR APPLICATION

RESEARCH AND DEVELOPMENT

Disabilities and consequent handicapping conditions comprise a complex and varied array of etiologies, diagnoses, and prognoses. It is clear that science and technology can make, and are making, important contributions to the prevention of some kinds of disability. For example, vaccination against poliomyelitis has reduced occurrences of paralysis, and the rubella vaccine forestalls many prenatal defects; head rests and seat belts are effective in the prevention of whiplash and other injuries. Science and technology also contribute to the amelioration of irreversible losses. Hearing aids, artificial limbs, and stroke therapies using electrical stimulation of muscles are examples of these contributions, and there are many others.

In order to better assess how a more thorough, vigorous, and enlightened attack by science on handicapping conditions might be mounted, it is useful to reflect on the process of scientific research, development, and evaluation, and on the subsequent product or process realization as they apply to this field.

Basic versus Applied Research

The business of science is the search for new knowledge. A useful partition of research is into basic or fundamental research versus applied or goal-oriented research. Both are vital in the advance against handicapping conditions.

Basic research tends to follow disciplinary lines, leading the investigator wherever the theory or data take him. Although nonspecific to handicapping conditions, basic neurophysiological research into the central nervous system, for example, leads to sensory input and motor control information central to cybernetic limb prostheses and sensory orthoses. A greater awareness by neurophysiological investigators of the prevalence and importance of handicapping conditions and their causes could direct some basic research into areas of great potential benefit to the relief of the handicapped.

For example, mechanisms underlying cutaneous sensibility are a focus of basic research, but relatively few of the basic scientists investigating cutaneous sensibility are aware of the implications of their work in relation to relief of the handicapped. For the sight- or hearing-impaired, sensory inputs delivered via the skin provide a possible alternative route that might substitute for defective eyes or ears. To be most useful in the design of surrogate sensing devices, basic information concerning sensory

pathways must expand to answer additional questions of particular value in application. What is the capacity of the skin and brain to acquire and interpret multidimensional dynamic information presented via vibrotactile or electrodermal stimulation? The point is that the basic research questions must be addressed to the human system--not only in its normal state or in specific disease and trauma states, as is now done, but also to the handicapped human system.

If basic research is to broaden in this direction, the viewpoints and techniques of the physical sciences and engineering must be integrated more effectively into the dominantly biological and biochemical medical research milieu. Amelioration of handicapping conditions will often involve the augmentation of the disabled human with a machine that becomes part of his person. Thus basic research, when appropriate, must broaden the usual partitioning and penetrating style of science to include the more comprehensive and integrative systems approach essential to the understanding of man-machine systems.

The boundary between basic and applied research, however, is almost always somewhat blurred.

In contrast to the search for new knowledge, applied medical research identifies a specific need in a target population and designs a device or therapy to satisfy that need. But, for example, research in prosthetics does not necessarily begin that way. Instead, it may begin in relation to theoretical aspects of cybernetics,* just as much biomedical research relates to fundamental knowledge in biochemistry. For example, research on multiple-degree-of-freedom, power-driven, upper- and lower-limb prostheses with force and position feedback using electromyographic signals on the man-machine interface should be classified as basic research, at least for the present.

In spite of this inevitable blurring at the boundary, it is important to distinguish between basic and applied research in the study of disability for several reasons. First, if a product of basic research is evaluated purely by its success in satisfying a practical need, then a project that has led to new and important basic knowledge may be judged a failure. Second, if a device that is the product of basic research is applied too soon, the result may be compromised, and the device may be of little value for either basic or applied research.

Finally, it is counterproductive to release research models of prostheses still in the prototype stage of development when there are unwarranted expectations as to actual clinical utility. This does not mean that one should avoid testing laboratory prototypes on human subjects. Rather, it means that the outcome of such testing should be evaluated in terms of new knowledge acquired as well as in terms of clinical utility.

*Cybernetics is the science of communication and control in the animal and in the machine, especially the mathematical analysis of the flow of information in such systems.

In addition, it is important to recognize that basic prosthetic research may be of value to patient populations other than those for which the research prototype devices were initially intended. For example, many of the ideas coming from limb prostheses servocontrol may be applicable to motor disorders such as parkinsonism, cerebellar ataxia, and other neurological disorders.

In summary, it seems clear that prosthetics research should continue, but that care should be taken to avoid unjustified expectations for near-term application. Thus, in the field of limb prosthetics, the existence of a field of basic research on the cybernetics of human movement should be recognized, and it should be supported on the same level as are other fields of basic biomedical research.

Device Development and Evaluation

All devices must undergo a thorough development process to ensure that they meet functional and technical requirements and are reliable and safe for human application.* In addition, economic feasibility must be demonstrated if the product is to prove useful. Evaluation must permeate the entire research and development process. When the device reaches the point where functional, practical, reliable units exist in multiple, but not numerous copies, serious field evaluation must be undertaken to show clinical and economic feasibility.

Evaluation at this stage should be comparative: it must focus on the contribution to user performance that the aid provides in reference to a baseline of (a) existing, more traditional means for reading, mobility, and so on, (b) a comparison of competitive devices, or (c) modifications of the same device.

Evaluations should also be structured so that both anticipated and unanticipated results can be fed back into improvements of the device. Evaluation should strive to identify information that could prove beneficial in variations of, or perhaps even radical departures from, the specific concept under evaluative study. An evaluation should define the needs the device can fulfill, and identify segments of the population that will find the device most useful and those who will find it of limited utility. The process should also determine the nature and extent of training required to achieve effective use of the device by different segments of the affected population.

The question of who conducts the evaluation may confound one or the other of these desirable ends. The detection and remedy of faulty or improvable device features is most likely to occur with developer evaluation. But, given the identification of the inventor-developer and/or his organization with its product, evaluation must also become the responsibility of independent parties capable of objective but constructive assessment.

*The field of device evaluation is undergoing significant changes as evidenced by the Medical Device Amendments of 1976 (21 USC 301) to the Federal Food, Drug, and Cosmetic Act As Amended January 1975 (PL 94-295).

Once the multiple copies of the interim prototype of a product have demonstrated clinical and economic feasibility, the prototype must be transformed into a practical, manufacturable, durable product. Substantial redesign and production engineering are usually necessary during device development. Most often, the individuals and organizations who perform the research which results in new, ingenious devices are poorly equipped with experience in dealing with the development process. Furthermore, government agencies and private organizations that support research are themselves relatively unfamiliar with the nature and cost of product development.

For example, while the Department of Defense and the Atomic Energy Commission have had extensive experience in development (as well as in research) and maintain substantial in-house engineering capability through service-connected research and development organizations, the Department of Health, Education, and Welfare and its subsidiaries* have essentially no experience with the development process. Only a small nucleus of bioengineering competence exists in the National Institutes of Health, and in-house staff or facilities familiar with development are lacking.

Since the National Institutes of Health usually limit their scope to basic and clinical research, a policy that the President's Commission on Biomedical Research (32) recommends they continue, this gap is not as critical as it is in the Rehabilitation Services Administration, where the amelioration of handicapping conditions often presupposes a practical device. If the end product of research is the efficacy of some new biochemical agent, the drug companies are able to move into production. But if the end product of rehabilitation research is a device, there often does not exist a corresponding industry to develop and produce the device. This is because for individual devices the market is small and the risk of marketing failure is relatively high (see below).

Thus, a rational, systematic evaluation process should, logically, move from initial developer evaluation into independent assessment by disinterested but competent agencies or organizations. By this time the device's technical characteristics should be well established, and a training procedure should exist. With devices of known capabililty and reliability, and with an accepted training process, the frustration levels of trainers, trainees, and evaluators can be kept manageable, and the opinions and conclusions of groups operating simultaneously in different evaluation environments can be compared.

Device Availability to Users

If devices are ever to transcend being laboratory curiosities, they must be developed, evaluated, and produced in adequate quantities and

*Such as the National Institutes of Health, the Rehabilitation Services Administration and the Office of Education.

made available to potential "consumers." Traditional market mechanisms do not appear to be entirely adequate for this transition.

Several obstacles exist. There is no single large and insistent demand; instead, each potential recipient group by virtue of its particular physical impairment represents a relatively small potential market. Further, the economic means of the potential beneficiaries is restricted because of the disability. Available demographic statistics of potential user groups are quite inadequate for making market projections. Perhaps the most insidious obstacle is that the blind, deaf, and maimed do not politicize their inequalities, tending rather toward self-protection and introspection. Individual losses are so overwhelmingly great and currently available substitutes are so inadequate in comparison that victims tend to be wary of proposed panaceas even if they know of their existence.

Organizations that succor these victims are inclined, in turn, to be overprotective and inward-looking, fragmented and competitive among themselves, rather than outgoing, innovative, vigorous lobbyists for the interests of their memberships. Furthermore, the market is usually not a simple supplier-consumer relationship. Where medical prescription is necessary, as in orthopedic and ophthalmological devices, the supplier is often dealing with a doctor or a paramedical specialist rather than with the ultimate consumer. This is not a very exciting market prospect from a commercial point of view, considering the substantial costs of market penetration.

Even when federal or private funding sources support product development, choosing a potential product to underwrite is difficult. Development and market introduction costs range from ten to one hundred times the research feasibility investment. Since only a small proportion of research projects lead to marketable products, the cost ratio of development to research is very high. Developmental efforts cannot compete in total cost with the many diversified research proposals. Support of research is easier, safer, and cheaper.

The route from early feasibility studies into wide-scale deployment is often blocked by the frequently insuperable obstacles represented by product and market development.

A possible resolution to these difficulties might be the formation of a private-public corporation charged with the development and market introduction of really promising rehabilitation engineering products. The central problem is the lack of venture capital. A combination of government, industry, and organizational funding could provide adequate resources to start the process with the most promising candidates. Choosing particular products is difficult, but a separate corporation with its own organization free of direct influence from the network of federal and private agencies that support and do research, would ensure objective choices.

The management resources of such a corporation should include individuals knowledgeable about the relevant medical and/or rehabilitation fields, market analysis and estimation, production procedures and costs, distribution, sales, and so on. The actual makeup of the corporation might range

from a competent but small managerial team (that subcontracts tasks to existing organizations) to an overall in-house competence. Such an organization must not be permitted to assume a persistent role in the routine manufacture and sale of successful products (where success implies market acceptance and realized or potential profitability). Its central focus must be with the transition from research through deployment, after which it must divorce itself from success in order to commit its resources to new opportunities.

The manufacture, distribution, and sale of successful products must be assumed by private enterprise. Exclusive licensing arrangements could prove an incentive to industry to assume products. Pay-back royalties or provisions from sales could, over time, renew the venture capital resources of the proposed developmental corporation.

The Swedish model for negotiating this route is instructive (25). First, the Swedish Board for Technical Development finances on a pay back basis industrial research and development for products that have commercial potential, especially if they are unique and have export prospects. Second, under the National Health Program, all aids and prosthetic devices, evaluated and approved by the Institute for the Handicapped, are provided free to the user, thus guaranteeing a market to the manufacturer. Third, in order to finance the pilot production needed for initial evaluation, one percent of the total national budget for the purchase of devices is available to manufacturers on a competitive basis, with allocation decisions made by the Institute for the Handicapped and by the Ministry of Health. In FY 1975-1976, the total Swedish government cost for all services to the handicapped population of over one million persons* was $1.2 billion or 1.8% of the gross national product. Of this, $68 million was used to purchase free aids for the handicapped, $1.4 million for government funding of research and development for the handicapped, and $0.23 million on government support for the introduction of developed aids.

A somewhat comparable incentive could be created in the United States if, when national health insurance is legislated, provision is made for approving and providing appropriate rehabilitative devices as part of health care. This could extend the current provisions of the Veterans Administration to the general population. The organization of the health care system and how it relates to the care of the handicapped population in the U.S. is discussed by Charles Edwards in Volume 2 of this report.

BLINDNESS AND LOW VISION

Vision is the primary channel of communication between the individual and his environment, both for utilitarian and aesthetic purposes.

*In the same year the population of Sweden was 8 million and the total government budget was $23 billion. Data from Birger Roos, Technical Director, Swedish Handikappinstitutet, August 24, 1976.

The Problem and Population

The provision of practical substitutes for vision has two primary objectives: access to the printed page and unhampered mobility in a normal environment. It is worth noting, however, that many other applications of visual communication are also quite important. These range from sign reading to gesture observation, from graphic and pictorial instruction to scenic and artistic enjoyment.

Sensory aids that equip a blind person for reading text or for moving effectively in unfamiliar surroundings must extract complex information from the environment and present the pertinent aspects to the user through one or more of his remaining sensory channels. Because the ear has only 40,000 nerve fibers into the brain in contrast to the approximately one million nerve fibers between the eye and the brain, the ear compares poorly with the eye as a sensory organ. Similarly, the six-line resolution of the fingertip compares poorly to a 525-line visual television image. Thus, adequate sensory-aid replacement of the functions of the complex neural networks of visual systems obviously will require extensive fundamental knowledge and extremely sophisticated system design.

As discussed in Part II of this report, the scope and quality of demographic statistics on the visually impaired are poor. For the United States, estimates of the number of legally blind vary from 300,000 to 450,000 while the National Health Survey estimated in 1965 that 1.7 million were functionally blind. In spite of gross discrepancies in estimates, it can be concluded that the population of the visually impaired is indeed large.

Costs of Visual Impairment

The total annual income lost nationally by blind and visually impaired persons has been estimated at above one-half million dollars, based on the total blind population and on the median incomes earned by comparable age groups in the sighted population. As pointed out in Part II of this report, estimated total costs for services to the blind are in the hundreds of millions of dollars. Sensory aids programs and research to improve sensory supplements could transform blind persons from lifetime dependents or marginal income-earners to taxpayers who amply return the government's investment in rehabilitation.

Given the difficult and unique goals implied by a sensory-aid orthosis, a coordinated program responsive to the needs and capabilities of the blind is essential if substantial progress is to be achieved.

Aids for Complete or Nearly Complete Blindness

Non-visual Reading Aids. A highly desirable type of reading aid is one that accepts ordinary printed material, recognizes the alphanumeric characters, and produces natural speech. It has obvious advantages in

terms of speed and familiarity, but it requires complex equipment and sophisticated processes. A prototype of such a device is being developed. To offset the difficulties of complexity and cost several simpler devices have been developed.

The first of these is a direct-translation unit that converts the output from an array of photocells into a simple one-dimensional auditory display or into a two-dimensional facsimile (tactile) display for tactile reading. These devices have been technically within reach for the last decade or so, and recent developments have made feasible the volume production of small, highly portable units at relatively low cost. The performance of the present direct-translation units is hampered by inherent limitations in the crude transformation the device offers to the user's sensory and perceptual processes. Presumably the main difficulty is information loss. Research to improve device design and optimal training procedures has had moderate success. Nevertheless, a direct-translation aid is of value to some blind people in certain limited but important situations. For example, independent textbook reading has been shown to be not only possible but quite enthusiastically received by students.

There also has been great interest in more elaborate machines to recognize individual characters and produce some auditory or tactile signal for the blind user. This implies two quite different technological problems: character scanning and recognition, and the generation of a new corresponding symbol or other linguistic signal in another sensory modality.

The first problem, that of optical character recognition, has received considerable commercial development in recent years. Simple systems exist that read only the ten digits and a few other symbols in a fixed-type style and format. Others are elaborate computer-coupled multimillion-dollar systems that read multifont typewritten characters at high speed and with great accuracy without human intervention. The simpler machines are not useful because of their limited scope, and the more versatile systems so far are too expensive.

A type of reading aid on a level between a direct-translation device and one that can generate synthetic speech is receiving increasing attention. This intermediate aid contains electronic logic for recognizing printed letters, allowing a spelled-speech output. Despite the low speed and accuracy requirements, the design of a low-cost character recognizer presents many technical difficulties; progress, however, is being made in this direction in at least two laboratories in the United States.

Recent technological advances have made small and relatively inexpensive speech synthesis devices feasible. For example, talking pocket calculators are now available. More elaborate and costly advances use computer pattern-recognition techniques in conjunction with speech synthesis to permit the direct translation of printed English into audible speech for the blind user. The economics of such elaborate systems are still prohibitive, but the technological breakthrough of this old dream for blind prostheses has been made.

Mobility Aids. The problem of conveying sufficient information about a blind person's surroundings to enable him to navigate safely is probably the most difficult in the whole sensory-aid area. Unlike printed text, the input is not well restricted, and it is not always possible to define what constitutes relevant information. Also complicating the problem is the possibility that the individual's perceptual concepts of space undergo a radical change with the onset of blindness. In the case of the congenitally blind, three-dimensional spatial awareness may be distorted. Thus, the conventional perceptions of sighted persons may be of limited usefulness in assessing important features of space as interpreted by the blind.

It is commonly agreed that all mobility aid devices so far developed fall far short of providing the blind with complete mobility. It is interesting, however, to contrast the enthusiasm of an active minority of blind persons with the pessimism of certain psychologists whose task it has been to evaluate a user's performance with a particular device. We may, in part, be observing the well-known and understandable proclivity of subjects to perform better when they are receiving unusual attention. These subjects' appraisal must be contrasted with the investigators who must compare the ease, speed, and effectiveness of proposed mobility substitutes with those of the cane and the guide dog.

The concept of providing a direct-translation view of the environment by translating a simple light pattern to a tone (or tactile) pattern output has been repeatedly reinvented. In addition to the problem of slow speed that plagues the application of this approach to reading, there are a great many other problems that are specifically related to mobility. These include infinitely variable scenic cues (compared to a few letters in reading), shifting perspective of given cues, and changing illumination. Probe-type detectors have, therefore, seemed more practical, in spite of their obvious limitations. Most designers have used relatively narrow beams requiring manual scanning of the environment and relying on proprioceptive feedback of hand, wrist, and arm position to convey spatial concepts. Some, however, envision automatic scanning and a map-like tactile output.

Several laboratories have built ultrasonic and optical-triangulation devices. One of these led to a laser cane. The current concept in this work is to preserve the many advantages of the long cane yet add tactile and audible signals giving early warning of objects (landmarks), stairs, or other major discontinuities of the terrain, and overhanging objects endangering the head and shoulders of the user.

An ultrasonic device developed in England in the early 1960s has been evaluated in many countries, including the United States. Used like a flashlight, it provides a complex auditory signal potentially allowing discrimination of target texture (hard walls and bushes, for example) as well as distance. An eyeglass-mounted binaural audiodisplay based on this concept is now commercially available. Psychological factors in selection of subjects and prolonged training appear to be important in the effectiveness attained with this device.

Another device using ultrasonic energy is carried on the chest like a small camera and explores the intended travel path of a blind user above and ahead of the area that he is probing with a cane. Early warning of sighted pedestrians and objects that could cause injury to his head or shoulders are examples of useful data acquisition by this system. The display is simple, and movement decisions can be made in ample time.

Numerous mobility aids have been built, but few designs have reached extended systematic trials. Thus far, such aids must be used in combination with the long cane. Some assist in simple "go," "no-go" output, sacrificing information to simplify training; others provide richer outputs requiring extensive training for full utilization. Thus far no device for the blind attempts automatic recognition of features of the visual field.

While many aspects of current mobility devices are still controversial, it appears that with greater refinement they could be made useful enough to be valuable in certain limited situations as supplements to the use of a long cane or guide dog. In addition, some of the devices may provide highly useful mental constructs of the three-dimensional world to congenitally blind children.

Direct Coupling to the Nervous System. It has been known for many years that direct electrical stimulation of the human brain in certain occipital areas can produce subjective sensations of light (called phosphenes) existing in visual space. The portion of visual space in which these phosphenes occur is sometimes predictable through a cortical map of the visual field. Based on these observations several researchers have attempted, in the last 10 years, to develop a prosthesis for the totally blind.

Such a prosthesis involves opening the posterior part of the skull by a neurosurgeon and placing an array of electrical stimulators on the brain surface. These are arranged to be activated electronically through the closed skull, permitting long-term experimentation. Various techniques have been used, but all permit sending repeated stimuli to any or several of the stimulators in the hope of producing a pattern of phosphenes that can be recognized by the subject as corresponding to an object in visual space.

There are few authoritative published reports of this work and publication time has been long. Most important, the results that are known are rather disappointing. In some cases the phosphenes have given extremely vague but repeatable geometrical information. In others, pattern recognition by the blind subject has not been achieved at all.

Data from some of the human (and many of the animal) experiments indicate that the potential for damage to tissues may be considerable. Sizable and frequently repeated electrical currents must be used. In addition, the physiological basis for experiments on the use of electrical currents to directly stimulate the surface of the brain is questionable.

These experiments are hazardous, difficult, and expensive. At present it is difficult to forecast the effectiveness of this approach as a rehabilitation technique.

Low-Vision Aids

There are many people whose visual acuity, even if maximally corrected with lenses, is not adequate for the performance of common tasks such as reading or sewing. Of this group of people with low vision, the more severely affected are legally blind. Many others who do not qualify as legally blind are nevertheless seriously handicapped. There is no precise definition of low vision; some cases are classified as such because of the task performance required. In an agrarian culture there are relatively few tasks requiring excellent acuity. In an industrial society such as ours, relatively slight diminutions in acuity will make certain occupations impossible. For example, a visual acuity of 20/100, hardly an inconvenience in guiding an ox-drawn plow, can be an insuperable difficulty for a machine tool operator. Low vision occurring among the elderly, as it often does, goes unreported in a large percentage of cases. We do not know the true extent of this handicapped population, but it greatly exceeds the number of legally blind.

The diseases resulting in low vision are, in general, those that diminish the function of the macular area (the central retinal zone that is represented in great detail in the brain) of the retina. In many cases of low vision the peripheral visual function is satisfactory. Thus, people with low vision may have little difficulty with mobility. They can reach the bus stop without help, but are then unable to discern which bus is approaching.

When we wish to discriminate fine detail within an object, we direct our gaze so that the object of regard is imaged on the macula, where the acuity is best. But when this acuity is insufficient, we must increase the size of those image details we wish to see, imaging them at greater magnification. We do this by bring the object closer to the eye.

We are so accustomed to adjusting image magnification on the retina to the practical task at hand that we may not appreciate its implications for the person with subnormal vision. A person with only 1/3 normal acuity will need to hold print at 1/3 the normal reading distance in order to make it legible. Legal blindness starts at 20/200, which is 1/10 normal acuity. The person with 20/200 acuity will need to hold ordinary reading material at 1/10 the normal reading distance, or about 1-1/2 to 2 inches from the eye. However, it is extremely difficult for the eye to focus on any object so close to it. Many normally sighted persons are familiar with the need for lenses to allow them to hold objects close enough for reading or other fine work. The problem is much greater for those who have to hold the work much closer.

The unusually strong reading lenses needed by people with subnormal vision are called low vision aids. In some cases they are fitted as eyeglasses;

in others they are held in the hand. The glasses leave both hands free, but create an uncomfortably short reading distance. The hand magnifiers are often more convenient, but allow the reader a smaller field of vision.

Improving the handicapped person's ability to resolve details in distant objects is much more difficult. This can be done with telescopes, but they are unsightly, expensive, and often very difficult to use. Telescopic aids are indicated in only a small percentage of low vision cases.

Closed circuit television can be useful when a large, nonportable, expensive system is compatible with the patient's situation. Magnification and contrast can be manipulated electronically in ways that make reading and writing easier with closed circuit television than with an optical aid.

Selecting the proper aids and ensuring that the patient uses them should not be a difficult problem for a vision care practitioner. But only a small minority of practitioners can do a significant amount of work in low vision because even those with suitable training and motivation cannot attend to the time-consuming needs of many of these patients.

With few exceptions, the devices needed by the visually impaired are simple, inexpensive, off-the-shelf items that industry knows how to make. What is needed now, even more than new technology, is wider availability of the benefits to be derived from current technology.

Conclusion

The scientific, technological, rehabilitation, and economic resources of the nation should be mobilized to provide an effective program to meet the needs of the blind and of those with low vision. Such a program should embrace research, development, evaluation, and deployment of aids for the blind, and severely visually impaired, as well as training in their use.

Research is required in three major areas:

assessment of information requirements of the blind;

assessment of human perceptual and sensory capabilities;

technological studies on the acquisition, processing, and display of information.

In addition, systematic evaluation of sensory aids to determine utility, to guide research, to feed back information for redesign, and to establish valid certification procedures should be carried out in

close collaboration with research efforts. For the vision impaired, reading and mobility are of prime significance. Research in these areas is of high priority. Results with reading aids are promising, but development efforts are needed. For mobility research, small-scale evaluation and experience with man-device interaction are urgently needed.

Finally, deployment studies of devices now ready for field trials by blind users are needed.

Support of research, development, and evaluation of aids for the visually impaired has been limited and should be expanded.

HEARING AND SPEECH

Communicative disorders can generally be defined as impairments of the abilities to hear and understand speech and to produce normal-sounding and understandable speech. These impairments have their physical bases in disorders of the ear, the vocal tract, and various brain structures. The physical disorders, in turn, can arise from a variety of causes, such as genetic and birth defects, infection, or trauma.

In considering the application of science and technology to hearing and speech, it is useful to divide the area into several broad categories of communicative disability. These are impairments of hearing, language, articulation, and voice.

Impairments of hearing and voice are primarily the result of peripheral disturbances. Language disorders, however, result primarily from disturbances within the central nervous system. Finally, disorders of articulation may result from both the above causes. Of course, disorders of hearing, language, articulation and voice may be combined. For example, hearing disorders may result in speech defects at any age and hearing disorders in childhood often result in impaired development of language.

While the exact numbers are difficult to specify, it is clear that large numbers of people suffer from communicative disorders (See also Part II of this report). Hearing impairment is one of the most common chronic physical disabilities with about 13 million affected (33). Brain disorders impairing communicative abilities and disorders of the vocal mechanism combine to produce substantial disadvantage in another 4-5 million. In 1970, the total direct costs per year for coping with communicative disorders has been estimated to be $500 million with an annual deficit in the earning power of the impaired of the order of $1,750 million (34).

Impairments of Hearing

People with impairments of hearing can be hard-of-hearing or deaf. Both the hard-of-hearing and the deaf require rehabilitation. Catlin (35) has recently reviewed the public health aspects of deafness and emphasizes that much work is needed in rehabilitation of the deaf and in the prevention of deafness. Of particular interest are the prevocationally deaf, defined by the National Assocation of the Deaf as:

> All non-institutionalized residents of the United States who have lost, or never had, the ability to hear and understand speech even when amplified this loss having been suffered prior to 19 years of age (33).

Catlin (35) cites the results of a national census of the deaf population showing that such prevocational deafness has an incidence of 2 per 1000.

A recent review by Hardy (36) emphasizes that hereditary abnormalities and perinatally acquired infections together account for most congenital hearing losses with known cause. Many cases whose causes are presently unknown, will also fall in these two groups as more is learned about them. Prevention of congenital deafness depends on identification of risk. Appropriately applied counseling and prenatal diagnosis, and diagnosis of some maternal infections have helped to prevent congenital deafness. Other preventive measures are the active immunization of girls and of susceptible non-pregnant women for diseases such as rubella. However, much remains to be done in this area.

One important area of progress has been improved behavioral (37) and electrophysiological (38) audiometry of children. Early diagnosis of hearing impairment is critical in the application of appropriate remedial measures to minimize communicative, developmental, and behavioral disorders that occur as a result of hearing loss. Such screening is particularly important to detect congenital hearing impairment. Improvement of audiometric testing of children, therefore, is one of the most important areas for the application of science and technology to the problems of the handicapped.

There is also a great need for improved audiometry of the adult patient's ability to perceive speech. Accurate speech audiometry is critical in the assessment of handicap, and in the evaluation of therapy. Such therapy may be medical, educational, or through the use of devices such as hearing aids or other sensory aids (39).

Once the hearing disorder is recognized, however, the problem of overcoming it remains. In an appraisal of the development of hearing aids, Carhart (40) points out that the basic characteristics of these aids have not truly changed since they were introduced in the 1930's. Wearable hearing aids as a class still function as conventional audio-amplifiers. Hearing aids are commercial products; thus, any changes they have undergone have resulted primarily from the pressures of business competition and the feedback of sales volume. Although engineers who have developed components

for hearing aids and those who have produced the final circuitry have striven to meet the needs of the hearing-impaired, the hearing aids of today are amplifiers of about the same capability as were the early vacuum-tube hearing aids. Major changes have been made in reduction of harmonic distortion, in the use of amplitude compression, in the role assigned to adjustable tone controls, in the slope of the frequency response considered optimal, in the miniaturization of the entire aid, and in added versatilities.

Major unresolved problems include: (a) selection of amplification pattern, (i.e., frequency response and amplitude compression), (b) frequency reallocation, (i.e., various forms of transposition), (c) improvement of signal-to-noise ratio, and (d) sensory substitution and associated new displays. Hearing loss is an extremely common physical handicap and is becoming increasingly common because the percentage of persons over 65 years of age in the population is increasing. More people, therefore, will be interested in improved hearing aids.

Recent studies (41, 42) indicate that improved speech perception is possible for many patients with sensorineural hearing loss. A disciplined research effort is needed so that step-by-step parametric investigations of speech perception by the hearing-impaired can be conducted, leading, perhaps to a theory that would allow specification of more functional design goals for hearing aids. There is obviously much room for progress, both in technological sophistication and in cost reduction, in relation to the distribution of hearing aids to the hearing-impaired.

Recently, there has been considerable interest in aids for the deaf that analyze speech (in its acoustic form) and provide visual or tactile displays. The designers of speech-training aids hope to improve the speed of training and the degree of naturalness achieved by deaf talkers, but so far these devices have not proved effective. Even when a speech problem is successfully corrected using a device, the corrected speech often does not "carry over" to everyday life. Nonetheless, there are indications that some of these devices may become useful with further research.

A speech-reading aid is designed to assist the lip-reader with the reception of running, everyday speech. For example, it has been repeatedly shown (43) that the higher-power hearing aid (when used under optimal environmental conditions) results in an improvement of lipreading scores of 10 percent even for the profoundly deaf because of the wearer's appreciation of the speech "envelope". Many deaf lip-readers should be able to improve their performance with aids more aptly fitted to their sensory capabilities than the current high-power aid. Thus, aids that analyze speech into different channels or banks of frequencies (vocoders) and display the "envelope" of each channel may be more effective than a high-power hearing aid for some subjects. Only recently two wearable devices have become available for testing (44). These differ both in the kind of speech analysis and in the kind of display that they provide. The Upton-aid extracts "features" of speech and displays them visually in an ingenious manner that allows the eye to be used for other activities, while the Saunders-aid divides the speech into various bands of frequencies and displays the amplitudes of each electrocutaneously. It is clear from a

variety of experiments that wearable visual and tactile aids will provide gains in speech reception for many deaf patients, especially the profoundly deaf (45). These gains may also be reflected in improved speech, as such aids may help the deaf person monitor his own speech. Therefore, it is important to move these kinds of devices from their present prototype stages of development into usable devices that can be given adequate clinical testing.

Possibilities exist for aids that apply electrical signals to the auditory nervous system via implanted electrodes (46). To date, it has not been possible to demonstrate gains in speech reception superior to those expected from the use of a simple vibrator. The implant approach has inherent risks and is costly because of the necessary surgery and medical care, and the engineering and development costs of the "transcranial" transmission of information and power to the stimulating units implanted in the head. Because of these difficulties, the implant approach does not seem as promising as other approaches in the near future.

Language

Disorders of language are diverse and complex; they are ordinarily associated with disorders of the central nervous system. However, it is often the case that perceptual or articulatory problems coexist along with disorders of language itself, thus complicating diagnosis and therapy. The rehabilitation of these patients is the concern of the field of speech therapy. Issues involved in language and speech rehabilitation of adult patients have been reviewed by Eisenson (47). The problems of children whose language development appears to be retarded relative to their general intelligence has been reviewed by Kleffner (48).

Because there is a wide spectrum of language disorders no simple summary of the problems confronting the speech therapist can be given here. It is generally recognized, however, that improved measurement of language development and language competence is needed to plan and evaluate therapy better. Of course, improved knowledge of neurophysiological correlates of language would be most helpful.

Articulation

Articulatory disorders arise from physical defects, neurological disorders of the speech motor centers and pathways, and from a variety of emotional and psychosocial factors. Often, especially in children, they arise for unknown reasons.

An example of an articulatory disorder resulting from a physical defect is that of the cleft palate (49). Progress in the treatment of cleft palate was slowed by lack of knowledge of the development of the structures of the vocal tract and by ignorance of the detailed muscular actions necessary to produce normal-sounding speech. Nonetheless, the combined efforts of

surgeons, speech scientists, and speech therapists now help such patients achieve nearly normal speech and appearance.

Poor articulation due to neurological defects has proven difficult to correct. Research presently under way suggests that greater knowledge of normal speech production and the application of this knowledge to strategies for training, including the use of biofeedback, may lead to an improvement of the speech of such patients.

Generally, improved correction of articulatory disorders rests on evaluation of existing therapies, improved knowledge of the functional anatomy of the vocal tract and of relevant parts of the nervous system.

Voice

Disorders of voice arise from poor vocal habits, psychopathology, and organic disease and trauma. An unclear or unpleasant voice has a negative impact on social interactions and on vocational options.

Ogura and Alonso (50), in a review of the developments in surgical and medical management of laryngeal disorders in the past 25 years, point out that there have been dramatic improvements in the study and treatment of laryngeal disease. Much of the work involved in rehabilitation of patients with laryngeal disease falls within the category of surgical and medical otolaryngology, and will not be dealt with here. An area of obvious relevance to the application of science and technology for the aid of the handicapped is that of the various devices used to allow individuals without a larynx to produce recognizable speech sounds. Such devices have been available for some time. These devices are to individuals with laryngeal loss as the hearing aid is to the patient with hearing loss. And just as the effectiveness of hearing aids seems to lag behind the potential inherent in current electronic sophistication, so too laryngeal aid technology has not enjoyed the type of intensive research and development possible today.

The devices available for production of voice in patients whose larynx has been removed are primitive. Quality is poor, power low, and pitch control is absent. The fact that such relatively primitive devices can be used by patients to produce understandable speech implies that there is a great deal of room for progress. With current technology, pocket-sized speech synthesizers are possible, and devices such as these may fill the need of a person made mute by disease or trauma.

Conclusion

Persons handicapped by communication disorders can be greatly assisted in learning to function with their handicap if better hearing, visual and tactile, and speech devices can be developed. Support should be provided so that research and development of these devices will progress from their present fragmented state into a disciplined effort focused on benefiting the handicapped without excessive cost.

To this end, adequate funds should be made available for development and evaluation of devices already in existence in the prototype stage (e.g., visual-tactile aids and improved hearing aids).

Evaluation of therapeutic techniques in and basic research relating to disorders of speech production and language need emphasis.

MANIPULATION AND LOCOMOTION

The numerous disabilities that limit a person's capacity to manipulate or move in his environment may be grouped in three broad categories: deformities (including amputation), paralysis, and skeletal joint destruction.

Deformity

The Amputated Limb. Amputation creates a profound disability because the losses are skeletal, muscular, and sensory.

Prosthetic replacement for amputated limbs has progressed from the simple to the sophisticated as engineering skills have advanced. Early devices merely replaced the skeletal segments so that a person could stand or fill a sleeve. Controlled activation was the second design phase, and sensory replacement is still in an early experimental stage. Durable covers with a more natural texture are also needed.

In the lower limb, the key to walking capability is knee control. A variety of hydraulic, pneumatic, or mechanical passive units provide stability during stance and restraint of unwanted motion in swing. However, timely activation of the stance control and initiation of swing depend on the physical ability of the patient to provide the appropriate body motion. The age of the patient and the number of limbs involved are very significant in prosthetic effectiveness. Only 10 percent of elderly diabetic patients with a single above-the-knee amputation are household walkers, while 55 percent of those with bilateral amputation below the knee have this capability. Controls that permit running, climbing, and so on, have not been provided for the young athletic amputee who has lost his knee. Amputations at the hip and higher levels present far more severe restraints. Thus, development of active control and appropriate feedback is still much needed for the lower-limb amputee.

For the upper limb, versatility is a critical need not filled by mechanical cable controls. Contemporary cable control mechanisms that harness gross trunk, shoulder, and opposite arm actions to prosthesis motion and position are too awkward, limited, and slow for all but a select few, who generally have an amputation below the elbow and specific job or avocational requirements that depend on prosthetic assistance. A second accepting group has been bilateral below-elbow amputees who would be totally dependent if they did not use prostheses. Infrequently does the above-elbow amputee persist with his prosthesis unless there are very specific needs.

A major step forward in replacing the versatility lost through upper-limb amputation has been the development of myoelectric control. The bioelectronic (electromyographic, or EMG) signals that accompany muscle contraction are used to control the motions of the prosthesis. Selective grasp has been provided effectively for the person with a below-elbow amputation, although he still must rely on mechanical adjustment or postural substitution for wrist and forearm positioning. The muscles providing these forms of control are in overlapping layers within the forearm and cannot be differentiated by surface electrodes.

Above-elbow amputations present a far more difficult challenge, with two areas requiring selective posturing: the elbow and the hand, with fewer control sites available. In addition, there is less opportunity to substitute for lost wrist and forearm motion. Experimental approaches toward solving this problem call on the natural synergies of the shoulder muscles, which tend to combine with key elbow and hand actions during selective tasks. One empiric technique employs passive* electrical resistance networks that relate EMG and joint motion according to patterns recorded during the performance of normal subjects. In contrast, a theoretically based technique feeds the surface EMG signals into a mathematical model that represents the salient features of the musculoskeletal anatomy, the geometry and kinematics of muscle origin and insertion in the bones, skeletal joints, and mechanical qualities of the contracting muscle.

Another area being explored for more selective control is the use of the neuroelectric signal detected by electrodes placed directly on peripheral nerves. This technique is subject to the limitation that the amplitude of the neural signal is one or two orders of magnitude below the amplitude of the signal from the surrounding muscle. The biocompatibility of implanted nerve electrodes is also a problem, but some progress is being made in this area. In acute experiments on animals, patterns of nerve signals have been shown to correlate with the corresponding contractions of muscle groups.

Amputation or paralysis not only deprives the patient of motor control but also deprives him of sensory feedback of limb movement and position. Sensory feedback research is still in the early experimental stage. Transduction of motion, position, pressure, and temperature in the artificial member is relatively straightforward, but feeding back appropriate information to the nervous system and brain has proved to be very difficult. Various types of skin stimulation, coding of direct neural stimulation, and long-term biocompatibility all need development.

Also of concern in limb prosthetics is direct skeletal attachment of the prosthesis to avoid the insecurity that soft tissues now impose between socket and stump. While materials compatible with bone are readily available, tolerable means of penetrating the skin have been difficult to identify. Motion at this interface continues to break the physiological seal, leading to eventual rejection of the foreign item.

*Invariant with respect to time.

Design and evaluation of novel limb prostheses call for close interrelationships between engineer, surgeon, prosthetist, therapist, and their good communication with consumers. The integration of diverse training backgrounds, vocabularies, and problem-solving strategies requires the explicit organization of project or institute structures.

The Intact Limb. Orthoses commonly are employed in the management of deformities of the intact limb. Their purposes are to assist with correction of contractures and to compensate for instability and malalignment of the limbs. All such devices provide the single function of static support. Considerable progress in mechanical effectiveness, comfort, and cosmesis has accompanied the introduction of plastic materials in such orthoses, particularly the vacuum-formed polypropylene.

Paralysis

Muscles have two equally important functions: the creation of motion and its selective restraint when joint stability is desired. Today's orthotic substitutes for paralyzed muscles serve primarily as stabilizers, restricting motion with locked or limited arc joints. Orthotic production of motion in flaccid limbs* is accomplished with springs and elastic bands. These forces are not strong, and can only be applied to the lower limb to pick up a drop foot. When used in the upper limb, however, they are helpful; in paralytic situations they permit an active antagonistic muscle to complete the arc of motion. Electronic and carbon dioxide "motors" also have been designed to produce motion in flaccid limbs, but they suffer the same limitations as prosthetics--difficulty in finding sources of remote control and lack of sensory feedback in anesthetic limbs.

A programmed, externally powered orthotic system has been designed to provide artificial locomotion. However, the lack of sensory feedback and the need for very massive power packets keep the system a laboratory model.

Patients with an upper motor neuron lesion (stroke, brain trauma, or cerebral palsy) have the unique opportunity to create motion through functional electrical stimulation. These persons have an intact peripheral neuromusculature that has been deprived of its normal central control. The initial development in functional electrical stimulation has resulted in a commercially available unit that activates the peroneal nerve to pick up the drop foot. This system incorporates a heel switch, a radio transmitter, and an indwelling electrode around the nerve. Extensive clinical trials in a number of rehabilitation centers have verified its effectiveness. The same approach has been applied occasionally to the femoral and gluteal

*Such as from destruction of motor units by anterior horn cell lesions (e.g., poliomyelitis), trauma to peripheral nerves, or muscle disease (e.g., muscular dystrophy).

nerves to control the knee or hip. Recently multichannel surface stimulation has been introduced to provide simultaneous hip, knee, and ankle control. This approach is experimental as several developments are still needed in order to coordinate stimulus timing with the patient's gait pattern. In the upper limb, functional electrical stimulation has been limited to re-education and contracture correction of a single muscle.

With an electronically controlled, articulated, bilateral limb orthotic system, walking between parallel bars has been accomplished by spinal-cord-injured patients. This approach is still experimental because balance is precarious in the absence of sensory input, trunk stability must be provided, and the massive energy requirements preclude portability of the orthotic system for the foreseeable future.

Muscle fatigue under electrical stimulation is a real problem, but current research indicates that desirable biological changes in muscle to increase its fatigue resistance can be achieved by systematic training regimes. An attractive alternative being studied is physiological recruitment of motor nerves via the spinal cord by direct multichannel afferent stimulation.

Skeletal Joint Destruction

Arthritic deterioration of joints has been a major cause of pain and disability for centuries. Orthopedic management of patients so disabled was revolutionized by the introduction of total hip-joint replacement. Artificial joints are available now for most areas of the body, either as commercial products or experimental models. Clinical success is most consistent in the hip because its normal anatomy (ball and socket) can be accurately reproduced with mass production techniques. This has not been true of joints in other areas of the body with more complex anatomy.

Three major problems must be solved before joint replacement can provide the ideal solution for skeletal joint destruction. These are control of surgical infection, secure fixation of the device within the bone, and more faithful anatomical contouring of the joints.

Infection accompanies the surgical insertion of the artificial joint in 1-10 percent of such cases and may cause the patient to lose rather than to regain function.

Loosening of the joint components from the bone is becoming more frequent as surgical success is encouraging the use of these devices in younger and more vigorous patients. The bonding agent, methyl methacrylate, is not a glue, but a biologically tolerated grout that provides fixation merely by filling all the interstices as pressure is applied during polymerization of the uncured mass. Bone accommodates to stress and becomes stronger when the stress is at a biologically acceptable level. Conversely, if the stress is excessive, the bone yields either by microfracture or gross fracture or by remodeling away from the force. The

static grout no longer matches the deformed contours of the host bone, and loosening of the device occurs.

A lesser problem in joint replacement is the replacement's failure to provide some of the functional qualities present in a normal anatomy.

The limitations of joint replacement make surgeons justifiably reluctant to use these devices until a patient is severely disabled. The consequences of such delay are loss of soft tissue mobility and muscle atrophy sufficient to permanently limit the potential of the artificial joint.

An alternative approach in relieving joint pain is the use of orthoses. These are effective if restraint of joint motion improves the patient's function. However, if this restriction necessitates substitutive postures or actions by other limb segments that are painful in themselves, the patient is not helped.

Conclusion

Current engineering technology allows persons with deformities, paralyses, or joint destruction to interact with their environment more successfully.

To improve devices necessary for motion in and manipulation of the environment, priority should be given to research and development of methods for control of prostheses and orthoses, methods to improve sensory feedback, hardware improvement, methods to attach devices to the operator, and cosmetic covers. The psychosocial acceptability of new or improved devices must be taken into account.

In the case of amputees, the application of current technology involves utilization of signals generated by the intact neuromuscular apparatus of the subject to control prosthetic devices. In addition, for patients with limb loss or spinal cord damage, current technology must be applied to wheelchair design, especially in the coupling of intact neuromuscular apparatus with the wheelchair.

Functional electrical stimulation can promote artificial locomotion and manipulation in patients with central paralysis. Thus, therapeutic systems to reactivate areas of neurological damage and to correct deformity require research and development, especially in the following areas: coordinated multichannel stimulation systems for both implanted and external use; reliable, miniaturized internal and external hardware; implanted programmed electronic control for both single and multichannel activators which can be modified externally without contamination; long-term reliability of widely dispersed intramuscular electrodes with the capability of alternating the area of activation; and prolonged, stable fixation of external apparatus.

Research and development in the area of skeletal replacement must continue to advance in the following areas: the development of more anatomical accuracy in commercial joints to provide better postural stability

and mobility; development of materials and bonding techniques better able to distribute load between bone and device during normal function; and development of better replacement devices for total or major segments of bone, ligaments, tendons, and fascial planes.

BASIC NEUROSCIENCE: REGENERATION AND/OR RECOVERY OF FUNCTION OF THE NERVOUS SYSTEM

The most compelling problems in human rehabilitation are those requiring a recoupling of brain function to the peripheral motor and/or sensory organs. Thus, our understanding of basic neuroscience underlies much of our future capability in rehabilitation. Of particular interest and relevance are (a) those aspects of neurobiology dealing with regeneration of the central nervous system, thereby potentially reachieving the lost connection; and (b) neuropsychology, which is concerned with replacing the functional capability of neurons that are no longer viable by intact portions of the brain that assume the lost functional role through adaptation and brain "plasticity" (51, 52, 53).

Aside from the very significant psychological aspects of overcoming a handicap (e.g., depression, lack of motivation), the ultimate conquest of paraplegia, quadriplegia, and disabling brain injuries awaits discoveries that will allow regeneration of the damaged nerve fibers in the spinal cord and brain. Since regeneration can occur in the peripheral nervous system, it seems entirely possible that recovery following transection of long tracts in the spinal cord may also become a reality someday.

Basic neurobiological research is currently being carried out on regeneration of the central nervous system. Studies on nerve tissue culture provide information on the requirements for growth and duplication of nerve cells. Such work may ultimately provide keys to understanding why neurons die and fail to regenerate following injury in adult human subjects. Neuronal "recognition" studies seek to define the process employed by growing axons to locate their appropriate area of "cell interaction" in mammalian brain development.

Clinical neuroscience expands our knowledge of the complex, interrelated cascade of pathophysiological and anatomical changes associated with spinal cord injury. These changes begin with immediate post-trauma hemorrhaging and edema formation, followed by myelin sheath and axonal disintegration and changes in vascularization and nerve conduction. Long-term paralysis and associated chronic problems, reinnervation of the bladder, prevention of calcification of muscle and joints, and maintenance of protein and salt metabolic balance remain important problems that follow paraplegia and quadriplegia and are amenable to clinical neuroscientific investigation.

Neuropsychology deals not with central nervous system regeneration, but with procedures that may be carried out to improve the functional capacity of individuals who have had lesions of the central nervous system. Even without regeneration of central nervous system tissue, as time progresses following the lesion there are great changes in functional capacity.

We do not yet fully understand how such plasticity works. We do know that damage to the nervous system early in life may be followed by considerable assumption of lost function by parts of the brain that remain intact.

Thus, in the case of individuals suffering from stroke and other cerebral disorders, there is great possibility for improved treatment by means of improving the rate at and extent to which remaining areas of the brain can assume functions that originally resided in tissue destroyed by a lesion. An interesting and important example of how new technology can advance neuropsychological knowledge and capability is that, with functional electrical stimulation for drop foot in hemiplegia, often the permanent benefit after removal of the stimulating electrodes is a brain reorganization in which the patient has been "retaught" to improve his gait.

The neurobiological and neuropsychological studies touched upon here indicate the kind of work that must be done if the handicaps resulting from brain injuries are to be reduced significantly.

The role of the neurosciences in the spectrum of physical disability makes it apparent that no sharp lines can be drawn between acute measures taken for the initial injury and the rehabilitative process that follows. Basic research in neurobiology and neuropsychology is relevant to both of these phases of treatment.

REFERENCES CITED IN TEXT

1. U.S. Department of Health, Education, and Welfare, Office of the Assistant Secretary for Human Development, Office for Handicapped Individuals. Federal Assistance for Programs Serving the Handicapped. DHEW Publ. No. (OHD) 76-22001. Washington, D.C.: U.S. Department of Health, Education, and Welfare, April 1976. 214 pp.

2. National Academy of Sciences, Institute of Medicine. National Survey Questionnaire Data, Part IV, Medicare-Medicaid Reimbursement Policies, Social Security Studies Final Report, 1976. (in press)

3. Ott, R., and A. B. Rossier. The importance of intermittent catherization in bladder reeducation of acute traumatic spinal cord lesions, pp. 139-148. In Proceedings of the 18th Veterans Administration Spinal Cord Injury Conference October 5-7, 1971, held in the Children's Hospital Medical Center of Harvard Medical School, Boston, Mass.

4. Haber, L. D. Disability Concepts: Implications for Program and Policy Development, pp. 21-29. In E. B. Whitten, Ed. Pathology, Impairment, Functional Limitation and Disability-Implications for Practice, Research, Program and Policy Development and Service Delivery. Report of the First Mary E. Switzer Memorial Seminar, Cleveland, Ohio, May 20-23, 1975. Washington, D.C.: National Rehabilitation Association.

5. Urban Mass Transportation Administration and Transportation Systems Center. The Handicapped and Elderly Market for Urban Mass Transit. Washington, D.C.: U.S. Department of Transportation, 1975.

6. U.S. Department of Health, Education, and Welfare, Public Health Service, Health Resources Administration, National Center for Health Statistics. Impairments Due to Injury. United States, 1971 National Health Survey. Series 10, Number 87. DHEW Publ. No. (HRA) 74-1514. Washington, D.C.: U.S. Government Printing Office, December 1973. 53 pp.

7. Frohlich, P., M. E. Burdette, R. H. Cormier, and M. T. Matthews. The 1967 National Survey of Institutionalized Adults. Residents of Long-Term Medical Care Institutions. Office of Research and Statistics, Social Security Administration, U.S. Department of Health, Education, and Welfare. DHEW Publ. No. (SSA) 75-11803. Washington, D.C.: U.S. Government Printing Office, 1974. 180 pp.

8. Organization for Social and Technical Innovation, Inc. Blindness and Services to the Blind in the United States. A Report to the Subcommittee on Rehabilitation, National Institute of Neurological Diseases and Blindness. Cambridge, Mass.: OSTI Press, 1971.

9. Mann, R. W. Technology and human rehabilitation: Prostheses for sensory rehabilitation and/or sensory substitution. Adv. Biomed. Eng. 4:209-353, 1974.

10. Schein, J. D., and M. Delk. How many deaf people? Rehabil. Rec. 14:36-38, 1973.

11. U.S. Department of Health, Education, and Welfare, Public Health Service, National Center for Health Statistics. Characteristics of Persons with Impaired Hearing. United States - July 1962-June 1963. Vital and Health Statistics. PHS Publ. No. 1000-Series 10-No. 35. Washington, D. C.: U.S. Government Printing Office, April 1967. 64 pp.

12. Rawlings, B., and A. Gentile. Additional Handicapping Conditions, Age at Onset of Hearing Loss, and Other Characteristics of Hearing Impaired Students. Office of Demographic Studies. Series D, No. 3. Washington, D. C.: Gallaudet College, 1970. 38 pp.

13. U.S. Department of Health, Education, and Welfare, Public Health Service, Health Services and Mental Health Administration, National Center for Health Statistics. Chronic Conditions and Limitations of Activity and Mobility. United States - July 1965-June 1967. Vital and Health Statistics. PHS Publ. No. 1000-Series 10 - No. 61. Washington, D. C.: U.S. Government Printing Office, January 1971. 72 pp.

14. National Paraplegia Foundation. Fact Sheet, 1972.

15. Haber, L. D. Epidemiological Factors in Disability. I. Major Disabling Conditions. Report No. 6. Social Security Survey of the Disabled: 1966. Washington, D. C.: U.S. Department of Health, Education and Welfare, Social Security Administration, Office of Research and Statistics, Feb. 1969. 24 pp.

16. U.S. Department of Health, Education, and Welfare, Public Health Service, Health Services and Mental Health Administration, National Center for Health Statistics, Rockville, Md. Use of Special Aids. United States-1969. Data from the National Health Survey. Series 10, No. 78. DHEW Publ. No. (HSM) 73-1504. Washington, D. C.: U.S. Government Printing Office, Dec. 1972. 23 pp.

17. U.S. Department of Health, Education, and Welfare, Public Health Service, National Center for Health Statistics. Distribution and Use of Hearing Aids, Wheel Chairs, Braces, and Artificial Limbs--United States, July 1958-June 1959. PHS Publ. No. 584-1327. Washington, D. C.: U.S. Government Printing Office, June 1961. 24 pp.

18. U.S. Department of Health, Education, and Welfare, Public Health Service, Health Services and Mental Health Administration, National Center for Health Statistics. Prevalence of Selected Impairments. United States-July 1963-June 1965. Vital and Health Statistics.

PHS Publ. No. 1000-Series 10 No. 48. Washington, D.C.: U.S. Government Printing Office, Nov%mber 1968. 78 pp.

19. Scott, R. A. The Making of Blind Men. New York: Russell Sage Foundation, 1969. 145 pp.

20. U.S. Department of Health, Education, and Welfare, Public Health Service, National Center for Health Statistics. Health Resources Statistics, Health Manpower and Health Facilities, 1969. PHS Publ. No. 1509. Washington, D.C.: U.S. Government Printing Office, May 1970. 286 pp.

21. U.S. Department of Health, Education, and Welfare, Public Health Service, National Center for Health Statistics. Health Resources Statistics, Health Manpower and Health Facilities, 1970. PHS Publ. No. 1509. Washington, D.C.: U.S. Government Printing Office, Feb. 1971. 362 pp.

22. U.S. Department of Labor, Bureau of Labor Statistics. Occupational Outlook for College Graduates, Excerpts from 1970-71 Occupational Outlook Handbook. Bull. 1681. Washington, D.C.: U.S. Government Printing Office, 1971. 257 pp.

23. Pilot, M. Health manpower 1980. Occupational Outlook Quart. 14 (no. 4): 2-3, 1970.

24. Social and rehabilitation services. Vocational Rehabilitation Programs. Implementation provisions. Fed. Reg. 39:42469-42507, Dec. 5, 1974.

25. The Swedish Institute for the Handicapped - A Survey. I/1974. Blackeberg, Sweden: Handikappinstitutet, January 1974. 14 pp.

26. Cooper, B. S., and D. P. Rice. The Economic Cost of Illness Revisited, p. 31, Table 7. Social Security Administration. DHEW Publ. No. (SSA) 76-11703. Washington, D.C.: U.S. Department of Health, Education, and Welfare, February 1976. 16 pp. (21-36)

27. Turen, M. The 1977 Budgets: President, Congress, and Health, p. 21. A Staff Paper. Washington, D.C.: National Academy of Sciences, Institute of Medicine, July 1976.

28. Executive Office of the President, Office of Management and Budget. The Budget of the United States Government. Fiscal Year 1977. Appendix, p. 379. Washington, D.C.: U.S. Government Printing Office, 1976.

29. National Academy of Sciences, National Research Council, Assembly of Life Sciences, Committee on Prosthetics Research in the Veterans Administration. Final Report of the Committee on Prosthetics Research in the Veterans Administration. Washington, D.C., 1976. 39 pp.

30. Levitan, S. A., and R. Taggart. Jobs for the Disabled. Washington, D. C.: George Washington University, Center for Manpower Policy Studies, June 1976. 159 pp.

31. Public Law 94-230, 94th Congress, H.R. 11045, March 15, 1976.

32. U.S. Department of Health, Education, and Welfare, Public Health Service. Report of the President's Biomedical Research Panel. Appendix A. The Place of Biomedical Science in Medicine and the State of the Science. DHEW Publ. No. (OS) 76-501. Washington, D. C.: U.S. Department of Health, Education, and Welfare, April 30, 1976. 261 pp.

33. Schein, J. D., and M. T. Delk, Jr. The Deaf Population of the United States. Silver Spring, Md.: Nat. Assoc. of the Deaf, 1974. 336 pp.

34. Carhart, R. Human Communication and Its Disorders. Monograph No. 10. National Institute of Neurological Diseases and Stroke, U.S. Department of Health, Education, and Welfare. Washington, D. C.: U.S. Government Printing Office, 1970. 176 pp.

35. Catlin, F. I. The public health aspects of deafness, pp. 313-324. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

36. Hardy, J. B. Congenital hearing defects, pp. 207-219. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

37. Lloyd, L. L. Behavioral audiometry with children, pp. 173-179. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

38. [illegible]is, H. Principles of electric response audiometry. Ann. Otol. [illegible] Laryngol. 85 (Suppl. 28):1-96, 1976.

[illegible]. [illegible]aan, T. W. Basic audiometry, pp. 191-198. In D. B. Tower, [illegible] The Nervous System. Vol. 3. Human Communication and Its [illegible]orders. New York: Raven Press, Publishers, 1975.

40. Carhart, R. Amplification for the hearing-impaired, pp. 291-297. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders: New York: Raven Press, Publishers, 1975.

41. Villchur, E. Signal processing to improve speech intelligibility in perceptive deafness. J. Acoust. Soc. Amer. 53:1646-1657, 1973.

42. Pascoe, D. P. Frequency responses of hearing aids and their effects on the speech perception of hearing-impaired subjects. Ann. Otol. Rhinol. Laryngol. 84 (Suppl.):1-40, 1975.

43. Erber, N. P. Trends in education for hearing-impaired children, pp. 305-312. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

44. Saunders, F. A., W. A. Hill, and C. A. Simpson. Speech Perception Via the Tactile Mode: Progress Report. San Francisco: Smith-Ketterwell Inst., 1976. 4 pp.

45. Pickett, J. M. Speech-processing aids for communication handicaps: Some research problems, pp. 299-304. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

46. Merzenich, M. M. Studies on electrical stimulation of the auditory nerve in animals and -an: cochlear implants, pp. 537-548. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

47. Eisenson, J. Language rehabilitation of aphasic adults: A review of some issues as to the state of the art, pp. 437-450. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

48. Kleffner, F. R. Language Disorders in Children. Indianapolis, Indiana: Bobbs-Merrill Co., Inc., 1973. 60 pp.

49. Morris, H. L. Evaluation of management regimes for cleft palate, pp. 525-535. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

50. Ogura, J. H., and W. A. Alonso. Advances in the surgical and medical management of structural abnormalities in the larynx, pp. 501-504. In D. B. Tower, Ed. The Nervous System. Vol. 3. Human Communication and Its Disorders. New York: Raven Press, Publishers, 1975.

51. Tower, D. B., Ed. The Nervous System. Vol. 1. The Basic Neurosciences. New York: Raven Press, Publishers, 1975. 685 pp.

52. Tower, D. B., Ed. The Nervous System. Vol. 2. The Clinical Neurosciences. New York: Raven Press, Publishers, 1975. 542 pp.

53. Stein, D. G., J. J. Rosen, and N. Butters, Eds. Plasticity and Recovery of Function in the Central Nervous System. New York: Academic Press, 1974. 516 pp.

GENERAL REFERENCES

Aitken, G. T., Ed. The Child with an Acquired Amputation. Subcommittee on Child Prosthetics Problems, Committee on Prosthetics Research and Development, Division of Engineering, National Research Council. Washington, D. C.: National Academy of Sciences, 1972. 162 pp.

Allan, K. H., and M. E. Cinsky. General Characteristics of the Disabled Population. DHEW Publ. No. (SSA) 73-11700. Washington, D. C.: U.S. Department of Health, Education, and Welfare, Social Security Administration, August 1972. 14 pp.

American Speech and Hearing Association. Resource Materials for Communicative Problems of Older Persons. Prepared by the ASHA Committee on Communication Problems of the Aging. Washington, D. C.: American Speech and Hearing Association, October 1975. 31 pp.

Brewer, G. D., and J. S. Kakalik. Improving Services to Handicapped Children. Summary and Recommendations. Prepared for the Department of Health, Education, and Welfare, Office of the Assistant Secretary for Planning and Evaluation. Santa Monica, California: Rand Corporation, May 1974. 52 pp.

Cinsky, M., and E. Steinberg. General Characteristics of the Recently Disabled. Disability Survey 71. Recently Disabled Adults. Report No. 4. DHEW Publ. No. (SSA) 76-11716. Washington, D. C.: U.S. Department of Health, Education, and Welfare, Social Security Administration, Office of Research and Statistics, April 1976. 44 pp.

Committee for the Handicapped, People to People Program. Directory of Organizations Interested in the Handicapped. Washington, D. C.: Committee for the Handicapped, 1976. 48 pp.

Dempsey, J. J. Congenital Malformations and Long-Term Care: Epidemiology, Service Utilization and Costs. A Preliminary Appraisal of the Literature. Working Paper No. 1. Washington, D. C.: U.S. Department of Health, Education, and Welfare, Office of the Assistant Secretary for Planning and Evaluation, Office of Social Services and Human Development, October 1974. 95 pp.

Dempsey, J. J. Cerebral Palsy: Epidemiology and Implications for Long-Term Care. A Preliminary Appraisal of the Literature. Working Paper No. 2. Washington, D. C.: U.S. Department of Health, Education, and Welfare, Office of the Assistant Secretary for Planning and Evaluation, Office of Social Services and Human Development, November 1974. 118 pp.

Dempsey, J. J. Selected Annotations on the Relationship of Prematurity to Handicapping Conditions and its Amenability to Intervention.

Working Paper No. 3. Washington, D. C.: U.S. Department of Health, Education, and Welfare, Office of the Assistant Secretary for Planning and Evaluation, Office of Social Services and Human Development, December 1974. 22 pp.

Haber, L. D. The Epidemiology of Disability: II. The Measurement of Functional Capacity Limitations. Social Security Survey of the Disabled: 1966. Report No. 10. Washington, D. C.: U.S. Department of Health, Education, and Welfare, Social Security Administration, Office of Research and Statistics, July 1970. 45 pp.

Kakalik, J. S., G. D. Brewer, L. A. Dougharty, P. D. Fleischauer, and S. M. Genensky. Services for Handicapped Youth: A Program Overview. Prepared for the Department of Health, Education, and Welfare, Office of the Assistant Secretary for Planning and Evaluation. Santa Monica, California: Rand Corporation, May 1973. 341 pp.

Kakalik, J. S., G. D. Brewer, L. A. Dougharty, P. D. Fleischauer, and S. M. Genensky. Services for Handicapped Youth: A Program Overview. Prepared for the Department of Health, Education, and Welfare, Office of the Assistant Secretary for Planning and Evaluation. Santa Monica, California: Rand Corporation, May 1973. 22 pp. (abridged)

Kakalik, J. S., G. D. Brewer, L. A. Dougharty, P. D. Fleischauer, S. M. Genensky, and L. M. Wallen. Improving Services to Handicapped Children. Prepared for the Department of Health, Education, and Welfare, Office of the Assistant Secretary for Planning and Evaluation. Santa Monica, California: Rand Corporation, May 1974. 329 pp.

National Academy of Engineering, Committee on the Interplay of Engineering with Biology and Medicine, Subcommittee on Sensory Aids. Sensory Aids for the Handicapped. A Plan for Effective Action. Washington, D. C.: National Academy of Engineering, December 1971. 27 pp.

National Academy of Engineering, Committee on the Interplay of Engineering with Biology and Medicine, Subcommittee on Sensory Aids. Selected Research, Development and Organizational Needs to Aid the Visually Impaired. Washington, D. C.: National Academy of Engineering, May 1973. 22 pp.

National Academy of Engineering, Committee on the Interplay of Engineering with Biology and Medicine, Subcommittee on Sensory Aids. Selected Research, Development and Organizational Needs to Aid the Hearing Impaired. Washington, D. C.: National Academy of Engineering, May 1973. 26 pp.

National Academy of Sciences, National Research Council, Division of Engineering, Committee on Prosthetics Research and Development, Subcommittee on Sensory Aids, Evaluation of Sensory Aids for the Visually Handicapped. Washington, D. C.: National Academy of Sciences, 1972. 191 pp.

National Academy of Sciences, National Research Council, Assembly of Life Sciences, Committee on Prosthetics Research and Development. Mobility for Spinal-Cord-Impaired People. Report of a Workshop. February 22-24, 1974, held at the Rancho Los Amigos Hospital, Inc., Downey, California. Washington, D. C.: National Academy of Sciences, 1975. 193 pp.

National Citizens Advisory Committee on Vocational Rehabilitation. Report of the National Citizens Advisory Committee on Vocational Rehabilitation. A Report to the Secretary of Health, Education, and Welfare. Washington, D. C.: U.S. Government Printing Office, June 26, 1968. 115 pp.

Noble, J. H., Jr. Peer review: Quality control of applied social research. Science 185:916-921, 1974.

Rice, D. P. Estimating the Cost of Illness. Health Economics Series No. 6. Division of Medical Care Administration, Public Health Service, U.S. Department of Health, Education, and Welfare. Washington, D. C.: U.S. Government Printing Office, 1966. 131 pp.

Rutgers University, Bureau of Economic Research, Disability and Health Economics Research. Cost Burden of Disability and Effects of Federal Program Expenditures. Final Report. New Brunswick, NJ.: Rutgers University, November 1974. 180 pp.

Rutgers University, Bureau of Economic Research, Disability and Health Economics Research. An Evaluation of the Structure and Functions of Disability Programs. Year I Summary Report. New Brunswick, NJ.: Rutgers University, June 1975. 397 pp.

U.S. Department of Commerce, National Technical Information Service. Rehabilitation of the Physically Handicapped. A Bibliography with Abstracts. 1968-October 1974. Springfield, Va.: National Technical Information Service, 1975. 119 pp.

U.S. Department of Health, Education, and Welfare, Office of Human Development, Office for Handicapped Individuals. Long Range Projections of the Service Needs of Handicapped Individuals: An Interim Report. Washington, D. C.: U.S. Department of Health, Education, and Welfare, March 26, 1975. 281 pp.

U.S. Department of Health, Education, and Welfare, Office of the Secretary. Long Range Projections for the Provision of Comprehensive Services to Handicapped Individuals. Washington, D. C.: U.S. Department of Health, Education, and Welfare, Office for Handicapped Individuals, July 31, 1975. 48 pp.

U.S. Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Institute of Neurological Diseases and Stroke. Report on the Current Status of Research on Growth and

Regeneration in the Central Nervous System. Bethesda, Maryland: U.S. Department of Health, Education, and Welfare, March 7, 1975. 91 pp.

U.S. Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Eye Institute. Vision Research Program Planning. Report of the National Advisory Eye Council. Vision Research Program Planning Committee. Volume I. Introduction, Program Summary, and Recommendations. DHEW Publ. No. (NIH) 75-664. Bethesda, Maryland: U.S. Department of Health, Education, and Welfare, April 1975. 61 pp.

U.S. Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Eye Institute. Vision Research Program Planning. Report of the National Advisory Eye Council. Vision Research Program Planning Committee. Volume II. Research, Program Analysis. DHEW Publ. No. (NIH) 75-665. Bethesda, Maryland: U.S. Department of Health, Education, and Welfare, April 1975. 185 pp.

U.S. Department of Health, Education, and Welfare, Public Health Service, Health Resources Administration, National Center for Health Statistics. Prevalence of Selected Impairments. United States 1971. National Health Survey. Series 10, Number 99. DHEW Publ. No. (HRA) 75-1526. Washington, D. C.: U. S. Government Printing Office, May 1975. 64 pp.

Whitten, E. B. Pathology, Impairment, Functional Limitation and Disability--Implications for Practice, Research, Program and Policy Development and Service Delivery. Report of First Mary E. Switzer Memorial Seminar, Cleveland, Ohio, May 20-23, 1975. Washington, D. C.: National Rehabilitation Association. 33 pp.

Woods, G. E. The Handicapped Child. Assessment and Management. Philadelphia: J. B. Lippincott Co., 1975. 341 pp.

APPENDIX

WORK OF THE COMMITTEE

The National Research Council Committee on National Needs for the Rehabilitation of the Physically Handicapped held its first meeting in April 1975. During this meeting Dr. Thomas J. Kennedy, Jr., Executive Director of the Assembly of Life Sciences, and Dr. Artemis P. Simopoulos, Executive Secretary of the Division of Medical Sciences, briefly explained the history and the function of the National Research Council, and outlined the charge to the Committee. Dr. Franklin S. Cooper, Associate Research Director, Haskins Laboratories, and Dr. Gerhard Schmeisser, Jr., Chief, Orthopaedic Surgery, Baltimore City Hospitals, were invited guests.

The Committee members discussed their charge, which was threefold: (a) to assess the nation's needs regarding the application of science and technology to aid the physically handicapped, (b) to formulate a plan of action to meet those needs, and (c) to delineate the function of the National Academy of Sciences-National Research Council to best serve the nation's needs in this area.

The Committee began its work with plans for a workshop that would provide the members with expert views of the state of the art in several areas of rehabilitation research as well as information on agencies, issues, and organizations involved in rehabilitation.

The second meeting of the Committee was an intensive workshop, held during June 25-July 2, 1975, at Woods Hole, Massachusetts. Invited participants included scientific and technical experts in various areas of research related to rehabilitation, representatives of various federal agencies concerned with the physically handicapped, representatives of legislative groups, and handicapped individuals representing various consumer groups.

The Workshop sessions were designed to provide the Committee with the following information:

- A broad overview of the state of the art in research related to rehabilitation
- A picture of the organization of federal programs concerned with rehabilitation, particularly those involved with research and development
- An understanding of the legislative process through which laws concerning rehabilitation are enacted
- Insights into the way handicapped individuals perceive current rehabilitation capabilities in relation to their needs and what their expectations are from science and technology.

Topics covered in these sessions were: vision (low vision and blindness); agencies, issues and actions; communicative disorders (speech and hearing); locomotion and manipulation; multiple clinical needs of the handicapped; and the consumer's viewpoint.

At the conclusion of the Workshop, the Committee developed a preliminary report outline.

Funding problems necessitated a delay in the Committee's activities until April 3, 1976, when the third meeting was held. At this time the Committee members reviewed relevant events that had occurred since the Woods Hole Workshop. The Chairman reiterated the Committee's charge, proposed a detailed time schedule for completing the report, and appointed a Writing Subcommittee to undertake the task of compiling the sections of the report into a cohesive unit.

The Writing Subcommittee met on May 10, 1976, discussed each Committee member's written contribution, and reorganized the report to make it more concise.

At the fourth full Committee meeting on June 5, 1976, the work of the Writing Subcommittee was extensively discussed, and the Committee accepted the reorganized report. During this meeting the Committee discussed the lack of members in specific areas essential to the Committee's work, such as the social sciences. Because of time and financial constraints it was felt that it was impossible to expand the Committee membership or to hold several additional meetings. Therefore, the Chairman proposed that supporting papers be contributed by consultants in areas of expertise not represented by the Committee members. Subsequently, all of the persons who were invited agreed to submit manuscripts for the Committee's report. The topics and authors are: "The Limits of Cost-Benefit Analysis as a Guide to Priority-Setting in Rehabilitation" by Dr. John H. Noble, Jr.; "Public Policy Towards Disability--The Numbers, the Programs, and Some Economic Problems" by Dr. Monroe Berkowitz; "Social Issues in Rehabilitation" by Dr. Robert Morris; "Public Expectations" by Mr. Albert Pimentel; "Consumer Perspectives" by Mr. Albert Pimentel; and "Critical Issues Facing the Health Care System" by Dr. Charles C. Edwards.

The Writing Subcommittee, at a meeting on June 25, 1976, reviewed the Committee members' comments on the first draft of the report and revisions were made accordingly.

The final draft of the report was approved by the Chairman and by the Committee (by mail) in October 1976.

CONSULTANTS (PERSONS WHO ATTENDED THE COMMITTEE'S WORKSHOP)

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William Bean, Chief, Planning and Coordinator Unit, Office for Handicapped Individuals, Department of Health, Education, and Welfare, Washington, D. C.

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Franklin S. Cooper, Associate Research Director, Haskins Laboratories, New Haven, Connecticut

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David Dickson, Professor of Speech Pathology, University of Pittsburgh, Pittsburgh, Pennsylvania

Jack Duncan, Counsel, Subcommittee on Select Education, U.S. Congress, House of Representatives, Committee on Education and Labor, Washington, D. C.

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